July/August 2007

# Science & Technology Review

National Nuclear Security Administration's Lawrence Livermore National Laboratory

## Extreme Physics

*Also in this issue:*

- New Designs for Laser Targets
- Probing a Planet's Deep Interior
- How Stars Form the Elements
- Teller's Legacy in Plasma and Space Physics

## About the Cover

Experiments will begin at the National Ignition Facility (NIF) next year, and Livermore researchers are preparing for what many expect to be a new era of high-energy-density physics. This issue of *Science & Technology Review* looks at the projects already under way. The article beginning on p. 4 focuses on the basic science research that the Department of Energy national laboratories will pursue in collaboration with colleagues from universities throughout the world. A second article, which begins on p. 12, describes the innovative materials and techniques developed to make the millimeter-size targets for NIF experiments. Research highlights discuss the opportunities NIF will provide in astrophysics by replicating the extreme environments inside planets (p. 20) and in stars (p. 22). The stadium-size building on the cover houses all NIF components, including the target chamber (shown on the back cover), NIF's 192 laser beams, and more than 100 diagnostic systems.


Cover design: Amy Henke

## About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy's National Nuclear Security Administration. At Livermore, we focus science and technology on ensuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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July/August 2007

# Science & Technology REVIEW

Lawrence
Livermore
National
Laboratory


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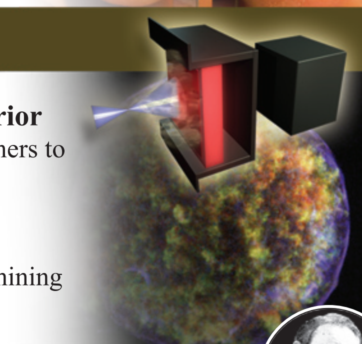



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### Tree location important in carbon offset projects

A recent study by researchers from Lawrence Livermore, the Carnegie Institution, Stanford University, and Université Montpellier II in France found that tree location is an important factor when considering carbon offset projects. This study, funded in part by Livermore's Laboratory Directed Research and Development Program, confirms that planting trees in the tropics could help slow global warming worldwide, but trees planted in mid to high latitudes could have the opposite effect. The research, led by Livermore atmospheric scientist Govindasamy Bala, appeared in the April 17, 2007, edition of the *Proceedings of the National Academy of Sciences.*

In general, forests affect climate in three ways. They help cool the planet by absorbing carbon dioxide and evaporating water to the atmosphere. Because they are dark, they also warm the planet by absorbing sunlight, a process referred to as the albedo effect. The collaboration's research found in the tropics the convective clouds that form when trees absorb carbon dioxide cool the planet. In mid- to high-latitude areas, the albedo effect is more prevalent. Deforestation in these areas may cause regional temperatures to be as much as 10 degrees cooler than they would be with the forests.

The authors warn, however, that deforestation in mid- to high-latitude areas will not alleviate global warming. In fact, destroying these important ecosystems would be counterproductive because they provide many benefits, including natural habitats, biodiversity, economically valuable timber, watershed protection, and indirect prevention of ocean acidification.

***Contact: Govindasamy Bala (925) 423-0771 (bala1@llnl.gov).***

### Study shows global warming effects on cereal crop yields

Livermore researcher David Lobell and Christopher Field from the Carnegie Institution researched the degree to which global food production has been affected by climate change. Their work, which was published in the March 16, 2007, issue of *Environmental Research Letters*, concluded that, on average, global crop yields respond negatively to warmer temperatures for several of the crops used in the study.

Lobell and Field studied climate effects on the six most widely grown cereal crops in the world—wheat, rice, maize (corn), soybeans, barley, and sorghum. These crops account for more than 40 percent of nonmeat calories in the human diet and more than 70 percent of animal feed. Between 1981 and 2002, the combined output of cereal crops throughout the world decreased by 40 million metric tons per year because of warming temperatures.

Using data from 1961 to 2002 provided by the Food and Agriculture Organization, Lobell and Field compared global crop yields with average temperatures and precipitation over the major growing regions. They then used the data to estimate the effect of the warming trends. For this study, the researchers assumed that farmers had not yet found methods for adapting crops to the temperature shift, such as planting crops that grow better in warmer climates. Their results indicate that yields have dropped approximately 3 to 5 percent for each 1-degree increase in temperature and that farmers must plant crops better suited for warmer climates to maintain sustainable production levels.

***Contact: David Lobell (925) 422-4148 lobell2@llnl.gov.***

### Researchers gain insight into nuclear isomer decay

A collaboration led by Livermore researchers has moved one step closer to turning on and off the decay of a nuclear isomer—a key capability for using isomers as high-energy-density storage systems such as batteries. The research team, which included scientists from Los Alamos National Laboratory and the National Aeronautics and Space Administration's Goddard Space Flight Center, studied an isomer of thorium-229 ($^{229}$Th). Because the excitation energy for $^{229}$Th is near the energy level for laser light, scientists may one day be able to use a tabletop laser to transition $^{229}$Th nuclei between its ground and isomeric states. Developing that capability could lead to scientific breakthroughs such as a clock with unparalleled precision for general relativity tests; a superb qubit, or quantum bit, for quantum computing; and diagnostic tests to determine how nuclear decay rates affect the chemical environment.

However, before researchers can attempt such exotic studies, they must precisely measure the isomer's excitation energy above the ground state. In the current study, the collaborative team used an indirect technique to make the most accurate measurement to date of the difference between the two states. According to Livermore physicist Bret Beck, who leads the project, the next step will be to tune a laser to the exact energy of the spacing so the transition can be observed directly. If that technique proves successful, researchers can focus on helping a transition from the excited isomeric state to the ground state—a process that gives off energy. Results from the team's research appeared in the April 6, 2007, issue of *Physical Review Letters*.

***Contact: Bret Beck (925) 423-6148 (beck6@llnl.gov).***

*Continued on p. 26*

# Dawn of a New Era

EXCITEMENT is building at the National Ignition Facility (NIF) and throughout the worldwide scientific community as Livermore researchers continue to commission laser beamlines and finalize experimental target designs. We are now just one year away from experiments using 96 laser beams and two years from experiments using NIF's full constellation of 192 beams. Already NIF is nearing 2 million joules of laser energy in the main laser beams, a factor of 40 more than the operating energy of the previous largest lasers. Ignition experiments are fast approaching. Our goal in these shots will be to demonstrate the fusion process by which more energy is released from a 2-millimeter-diameter target filled with deuterium–tritium fuel than is deposited by the input from the huge NIF laser.

NIF represents bold and courageous thinking, and it represents the tenacious goal-oriented behavior of our Laboratory. Almost 50 years ago, John Nuckolls and colleagues first pointed the way to thermonuclear burn using laser drivers.

What is different about NIF besides its size and capabilities? All previous laser facilities were built with what was then the latest technology. Scientists were challenged to develop their research objectives within the capabilities of the facility. In contrast, NIF was designed with research goals in mind. It will be operated specifically to meet the needs of three crucial missions: to strengthen stockpile stewardship for a safe and reliable nuclear stockpile, to show the feasibility of inertial confinement fusion (ICF) as a clean source of energy, and to make significant strides in high-energy-density (HED) physics to understand the basic physical processes that drive the cosmos.

These three missions share the need to prepare materials at extreme conditions—pressures of up to 10 billion megapascals, temperatures of 100 million kelvins, and densities of 100 grams per cubic centimeter. These conditions occur in exploding nuclear weapons, in supernovae, and in the fusion reactions that power our Sun and the stars. One day, they may provide an inexhaustible power supply on Earth. Two compelling books published by the National Research Council, *Connecting Quarks with the Cosmos: 11 Science Questions for the New Century* and *Frontiers in High Energy Density Physics: The X-Games of Contemporary Science*, defined the challenges of HED research and set the stage for experiments on NIF.

The next set of NIF experiments, designed to study the energetics of ignition targets, is scheduled to begin this coming winter. These experiments are called Eos, after the Greek goddess of dawn. Eos is a fitting name because NIF represents the dawn of a new era in physics research, especially in the fields of HED science and ICF.

As described in the articles in this issue, NIF will create conditions in a laboratory that will allow scientists to thoroughly probe and diagnose extreme states of matter. Scientific progress is typically characterized by many small steps, each enlarging and refining previous knowledge. With NIF, we expect to make significant advances in several disciplines in a relatively short time. NIF will permit researchers to study astrophysical phenomena that are now physically inaccessible. We cannot venture inside stars or planets or go near black holes. Neither can we traverse billions of light years across the universe to examine a supernova explosion. However, with NIF, we can re-create, on a vastly smaller scale, the same physical processes that astronomers can only glimpse through a telescope. For the first time, we will be able to study fundamental physics processes and attempt to answer questions that have intrigued scientists for centuries.

In 2010, when ignition experiments are scheduled to begin, scientists will mark the golden anniversary of the first working laser. Soon after this laser came online, scientists developed the concept of ICF. But the road to NIF really began well before the laser was invented. It started with the Laboratory's establishment in 1952. The vision of Livermore's cofounders, Ernest O. Lawrence and Edward Teller, set the stage for our success. Lawrence conceived of big science and multidisciplinary teams organized to tackle the biggest physics challenges. Teller had a passionate interest in basic science for strengthening national security and expanding scientific understanding.

NIF is on the path of the courageous vision of our founders. The work we do on NIF will be key to our future as a premier international research laboratory.

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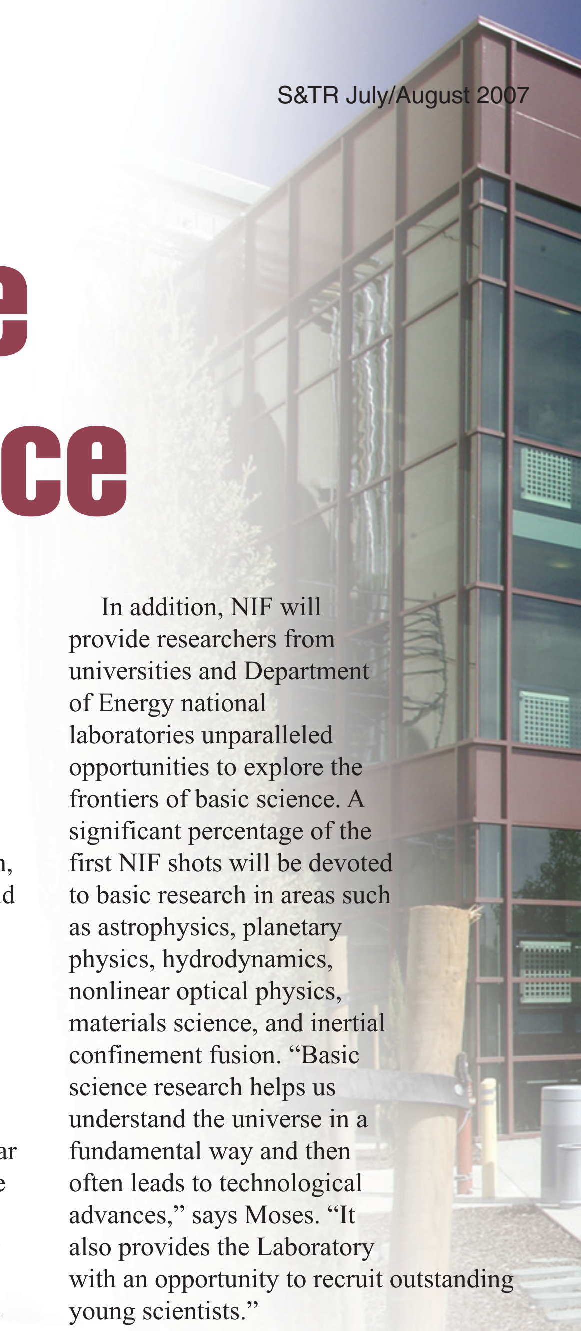
■ Edward I. Moses is associate director for National Ignition Facility Programs.



# Preparing for the X Games of Science

***Experiments on the world's most energetic laser will advance astrophysics, planetary physics, and other high-energy-density research.***

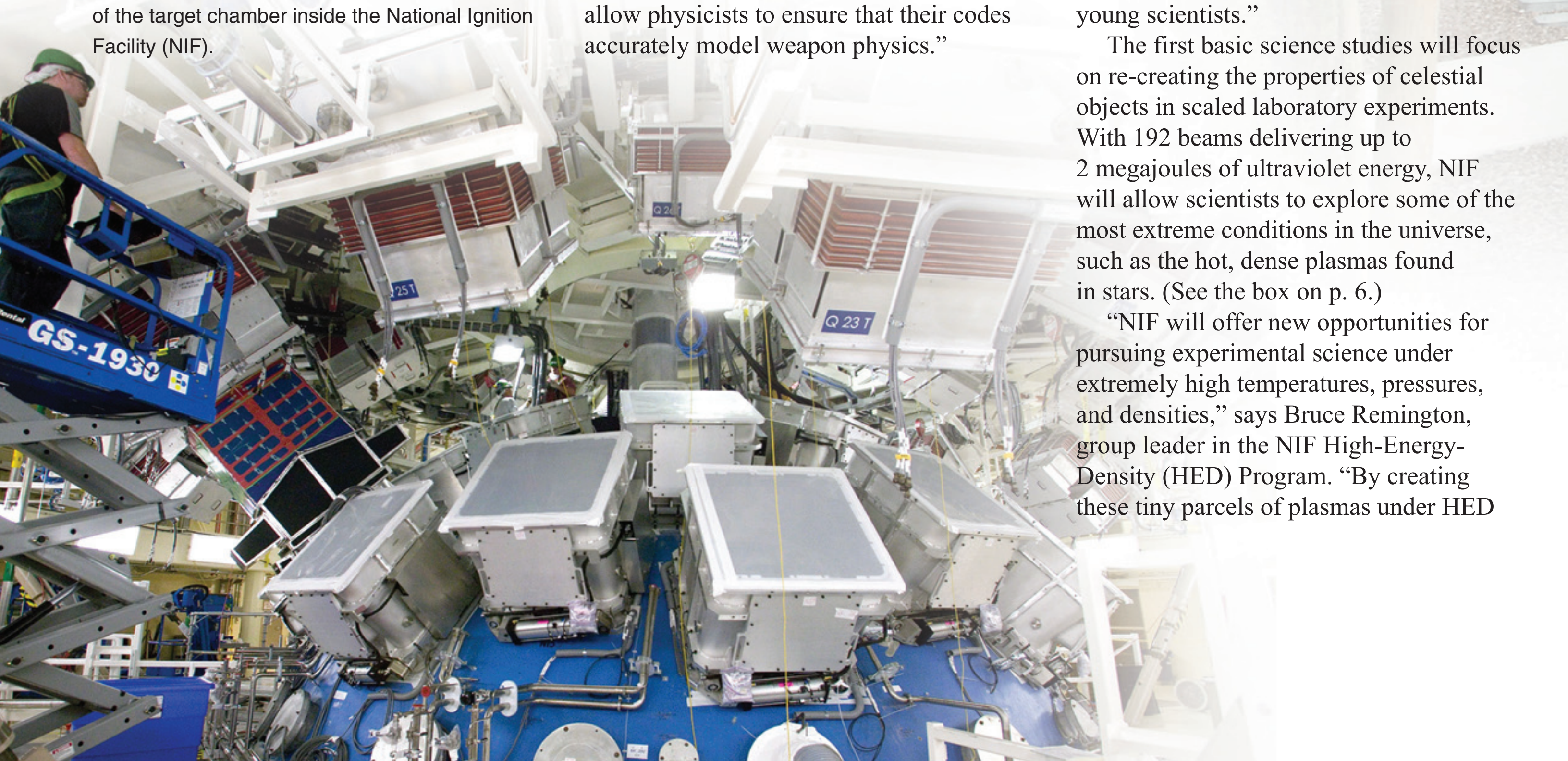
THE National Ignition Facility (NIF), the world's most energetic laser, is more than 90 percent complete, and scientists are preparing for the first experiments, which will begin in 2008. NIF's primary mission is to field experiments in support of the National Nuclear Security Administration's (NNSA's) Stockpile Stewardship Program, which ensures the continued reliability and safety of the nation's nuclear weapons.

"NIF experiments are an essential component of the nation's stockpile assessment and certification strategy," says Ed Moses, associate director for NIF Programs. "It is the only laboratory setting in which we can examine the physical processes that occur when nuclear weapons unleash their immense explosive power. The high-fidelity data acquired in these experiments will improve computer simulations of weapon performance and allow physicists to ensure that their codes accurately model weapon physics."

In addition, NIF will provide researchers from universities and Department of Energy national laboratories unparalleled opportunities to explore the frontiers of basic science. A significant percentage of the first NIF shots will be devoted to basic research in areas such as astrophysics, planetary physics, hydrodynamics, nonlinear optical physics, materials science, and inertial confinement fusion. "Basic science research helps us understand the universe in a fundamental way and then often leads to technological advances," says Moses. "It also provides the Laboratory with an opportunity to recruit outstanding young scientists."

The first basic science studies will focus on re-creating the properties of celestial objects in scaled laboratory experiments. With 192 beams delivering up to 2 megajoules of ultraviolet energy, NIF will allow scientists to explore some of the most extreme conditions in the universe, such as the hot, dense plasmas found in stars. (See the box on p. 6.)

"NIF will offer new opportunities for pursuing experimental science under extremely high temperatures, pressures, and densities," says Bruce Remington, group leader in the NIF High-Energy-Density (HED) Program. "By creating these tiny parcels of plasmas under HED




A worker helps complete the upper hemisphere of the target chamber inside the National Ignition Facility (NIF).


The entrance to the stadium-size facility that houses NIF.

conditions, we can better understand the physical processes that until now we've only been able to observe from afar."

Remington points out that researchers are confident the laser will be an effective HED platform because the 18-month-long NIF Early Light campaign was an unqualified success. This effort, completed in 2004, used the first four finished beams, called a quad, to conduct more than 400 shots while testing every component and system. Many of the 150 shots devoted to science led to published papers in top peer-reviewed journals, such as *Physical Review Letters*. "The laser performance during the NIF Early Light campaign was of startling quality," says Remington. "It worked incredibly well, which is promising for experiments we'll be doing on the completed facility."

### Spreading the Word

NIF experiments will help scientists understand the mechanisms at work in new stars, supernovae, black holes, and the interiors of giant planets. Livermore researchers have long been interested in the physical processes of stars because the primary mechanism involved in producing stellar energy is thermonuclear fusion—a process that is central to the Laboratory's national security mission. Since its founding in 1952, the Laboratory has advanced astrophysics by applying expertise in HED physics and computer modeling to examine the atomic processes that occur in these regimes. (See the highlight on p. 24.)

Numerous scientific organizations have cited the potential payoff from experiments on NIF and other HED facilities, such as the OMEGA laser at the University of Rochester's Laboratory for Laser Energetics and the Z machine at Sandia National Laboratories in New Mexico.

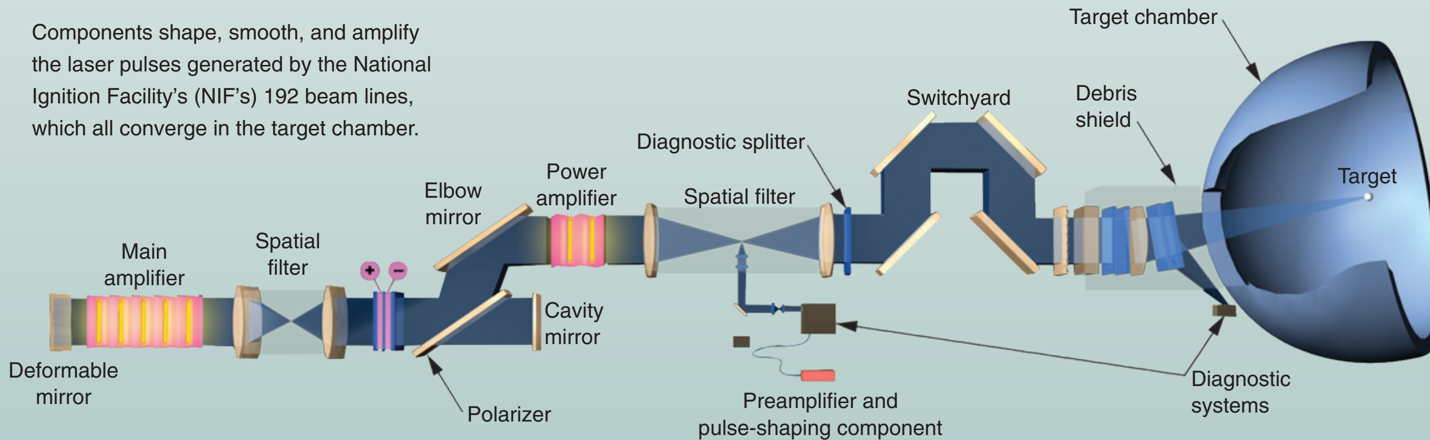
## Inside the National Ignition Facility

The National Ignition Facility (NIF) is the world's largest laser facility, and the combined power of its laser beams makes it the most energetic. NIF's 2 megajoules of energy—in a pulse of just a few nanoseconds—is comparable to about 500 trillion watts of power.

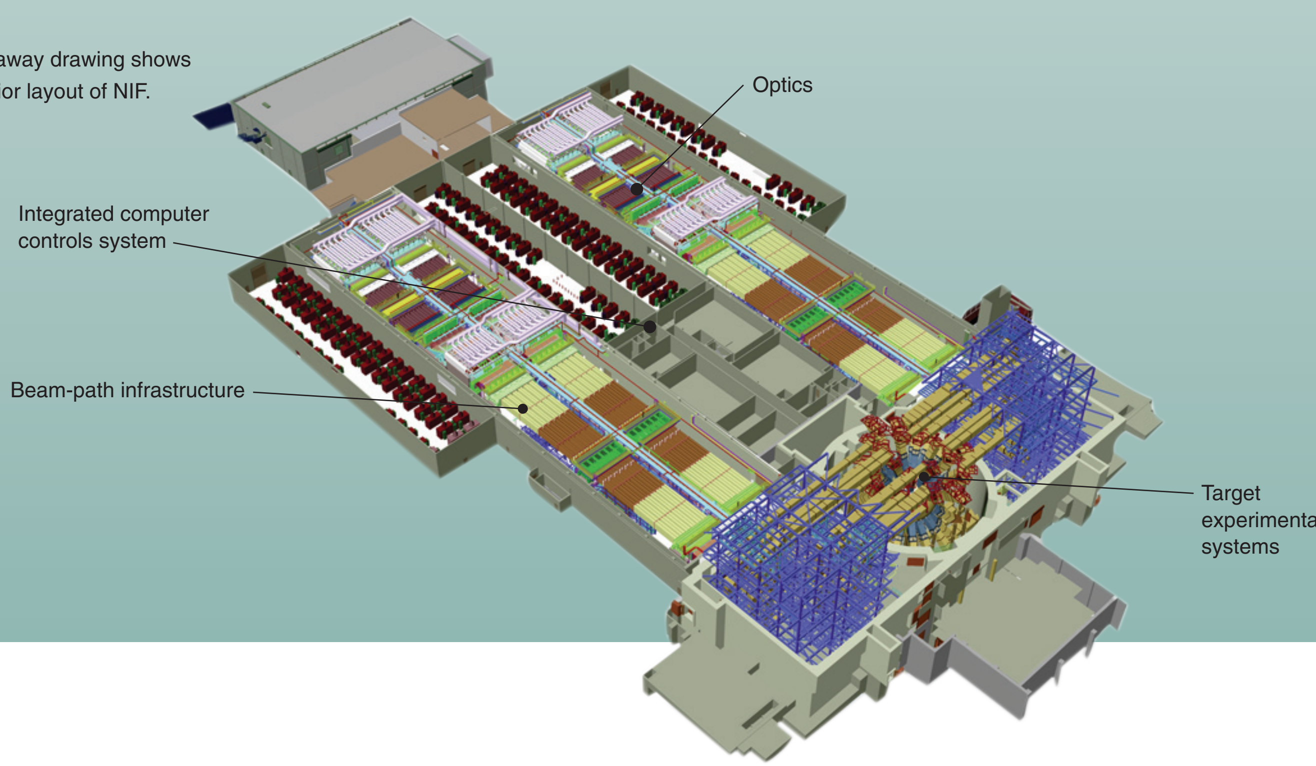
Inside NIF's stadium-size building, laser components shape and smooth an initial pulse, amplify it more than a quadrillion times, and direct it at a tiny target precisely centered in the target chamber. This process is replicated simultaneously 192 times, with all beams converging on the target chamber. More than 100 diagnostic tools can be trained on the target chamber to capture information about each experiment. According to Ed Moses, associate director for NIF Programs, NIF's impressive capabilities resulted from technological advances in laser systems, materials science, and engineering. "Without these breakthroughs," says Moses, "NIF would be far less capable or perhaps could not have been built at all."

The idea for NIF grew out of a decades-long effort to generate self-sustaining nuclear fusion reactions in the laboratory. Theorists, supported by years of experiments, have defined the temperature and pressure conditions required to compress and heat a capsule of deuterium–tritium fuel so that the fuel ignites and burns to produce energy gain. With these capabilities, NIF experiments will create physical regimes never before seen in a laboratory setting.

Components shape, smooth, and amplify the laser pulses generated by the National Ignition Facility's (NIF's) 192 beam lines, which all converge in the target chamber.




This cutaway drawing shows the interior layout of NIF.



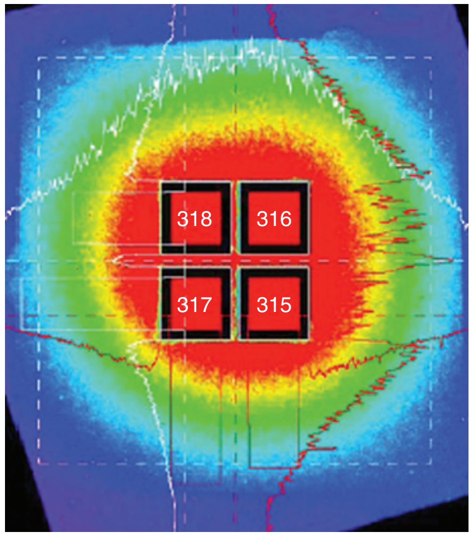
The National Research Council has termed experiments on these HED facilities "the X Games of contemporary science."

NIF managers are devising a detailed plan for engaging external participation and collaboration. Their goal is to turn NIF into a premier international center for experimental science, much like the Advanced Photon Source at Argonne National Laboratory or the Stanford Linear Accelerator Center.

"A broad scientific user community is critical to NIF's success," says Dick Boyd, science director of NIF Programs. "We're spreading the word about experimental opportunities." Boyd and other Livermore scientists plan to speak at American Physical Society meetings and other venues to outline NIF's capabilities and encourage participation. "We want to involve researchers who might not otherwise consider experiments on NIF," says Boyd.

Each proposal will undergo peer review by recognized experts in that particular field as well as a technical review by NIF staff. The most promising proposals will be forwarded to an independent committee of scientists from Livermore and other research centers and universities. The panel will recommend projects for NIF managers to approve. Says Boyd, "We're hoping to see proposals for prize-winning-caliber experiments."

Once a project is approved, its external principal investigator will work with a NIF liaison physicist to generate shot requirements and target specifications. The liaison physicist will serve as a point of contact between the external team and the Integrated Experimental Team in NIF's Physics and System Engineering organization, which will help implement the experiments. In addition, external users will be available to field their own diagnostics.




In an experiment during the NIF Early Light campaign, scientists precisely measured selected areas of light (denoted by four squares) from a quad of beams firing into a gas-filled hohlraum. The outer halo represents diffuse scattering of laser light. (Image courtesy of Chan Joshi, University of California at Los Angeles.)

### Three Teams Pave the Way

Three participating research teams received seed grants from Livermore to design configurations and targets for shots in HED regimes. The first team will study planetary interiors such as those found in Jupiter and Saturn. This team's principal investigator is Raymond Jeanloz from the University of California (UC) at Berkeley, and Livermore physicist Gilbert Collins is serving as the NIF contact. Other team members include Thomas Duffy from Princeton University, Russell Hemley from the Carnegie Institution, Yogendra Gupta from Washington State University, and Paul Loubeyre from Université Pierre et Marie Curie in France.

Former Livermore physicist Paul Drake, now at the University of Michigan, leads the second team, which will examine hydrodynamic processes, such as those that affect supernova evolution. Remington is the NIF contact for this team. Other members include David Arnett from the University of Arizona, Adam Frank from the University of Rochester, Tomek Plewa from the University of Chicago, and Todd Ditmire and Craig Wheeler from the University of Texas.

The third team will study laser–plasma interactions such as nonlinear optical phenomena—highly complex behavior that occurs when laser beams interact with large-scale plasmas. This team is led by Christoph Niemann, who holds the NIF professorship at UC Los Angeles (UCLA). Physicist Bob Kirkwood is the NIF contact. Other members include Chan Joshi and Warren Mori from UCLA; Bedros Afeyan from Polymath Research, Inc.; David Montgomery from Los Alamos National Laboratory; and Andrew Schmitt from the Naval Research Laboratory.

"We expect these teams to be among NIF's early science users and to help us work through external user issues," says Remington. A major goal for NIF managers is to find a mechanism for providing additional seed grants over the next several years so that other university teams can develop potential experiments for NIF.

One issue confronting the Laboratory is how best to manage site and electronic access for visitors while meeting NNSA's security requirements. A good model is the Jupiter Laser Facility, which provides an international academic community with access to its five laser platforms. (See *S&TR*, January/February 2007, pp. 4–11.) At Jupiter, teams of students, postdoctoral researchers, faculty, and other visitors conduct experiments under well-defined policies and procedures for safety, hazards control, and computer security. Livermore's Institute for Laser Science and Applications (ILSA) administers the Jupiter external user program. Each year, ILSA's director, physicist Don Correll, helps review several dozen proposals for Jupiter experiments. Correll will also serve as a reviewer of NIF proposals submitted by external investigators.

Because managers expect demand for NIF to be heavy, the Laboratory plans to adopt a staged approach to experiments. Before conducting full-scale experiments on NIF, research teams will test concepts,

## Hydrodynamic Instabilities in Supernovae

A core-collapse supernova marks the explosive death of a massive star. A longtime focus of Livermore research efforts, supernovae involve several physical processes, including nuclear physics, general relativity, hydrodynamics, and turbulence. Supernovae leave behind gaseous nebulae, neutron stars, or black holes. Scientists hypothesize that supernovae produce nearly all the elements in the universe heavier than helium and that supernova occurrences in or near clouds of cold, molecular gas may trigger the formation of new stars.

Before turning into supernovae, massive stars have a shell-like structure. Each shell from the core outward is increasingly lighter, and the "interfaces" between shells are marked by density changes. When a massive star runs out of nuclear fuel, its core, which is composed of the elements silicon through iron, collapses under the force of gravity. This catastrophic implosion lasts only a few seconds and triggers a powerful explosion that sends a shock wave back through the star. The violent reaction produces an enormous number of neutrinos and many complex hydrodynamic effects. The resulting stellar explosion appears as a bright flash of ultraviolet light followed by an extended period of luminosity that is initially brighter than the star's entire galaxy.

As the shock wave moves out through the star, it produces nonlinear hydrodynamic instabilities—processes that are similar to those occurring when a nuclear weapon detonates. In plasma hydrodynamic behavior, gases or plasmas act as fluids but also have electric and magnetic properties. Propelled by the shock wave, fingers of matter from heavier shells penetrate into and through the overlying lighter shells, characteristic of Rayleigh–Taylor hydrodynamic instability.

Supernova 1987A occurred in the Large Magellanic Cloud, a galaxy about 160,000 light years from Earth. The outburst, which was visible to the naked eye, is the brightest known supernova in almost 400 years. (Image courtesy of the National Aeronautics and Space Administration.)

The National Ignition Facility (NIF) will replicate shock-induced nonlinear hydrodynamic instabilities in scaled laboratory experiments. The spatial and temporal scales of NIF shots will be 10 to 20 orders of magnitude smaller than those of their astrophysical counterparts. The facility's flexibility and control systems will allow researchers to study the physical interactions with a new level of detail. "Several complex hydrodynamic problems are still unresolved, which affects our understanding of supernovae," says Livermore plasma physicist Bruce Remington. "A central question is why they explode at all."

Existing supercomputer models fail to explain the amount of material ejected from deep within a star into its surrounding layers. "To understand these processes, we must develop computer codes that examine the interactions in three dimensions," says Livermore plasma physicist Freddy Hansen. "It's a challenging problem even with the most powerful supercomputers."

NIF research will build on two-dimensional experiments by Hansen, Paul Drake at the University of Michigan, and colleagues from the University of Rochester, University of Arizona, State University of New York at Stony Brook, and University of Chicago. In experiments with the OMEGA laser at the University of Rochester's Laboratory for Laser Energetics, these researchers used a cylinder of beryllium, called a shock tube, filled with a layer of plastic and a layer of aerogel foam separated by a sinusoidal interface. Laser beams directed at one end of the cylinder propagate a shock through the two layers of material. The shock triggers Rayleigh–Taylor instability, which drives finger-shaped extensions of the plastic to penetrate the aerogel foam. Similar instabilities occur when the heavier inner shell of a massive star is decelerated by the lighter material nearer its surface. The subsequent hydrodynamic mixing is measured by x-ray backlighting. With this technique, some of OMEGA's 60 laser beams strike a separate disk to create an x-ray source, and the x rays generated are recorded to capture a detailed impression of the plastic layer penetrating the foam.

In a NIF experiment proposed by the Drake team, a hemispherical target of two or three increasingly lighter shells will experience a shock wave lasting 50 to 100 nanoseconds or longer, thereby causing turbulent hydrodynamic mixing. A pulse of energetic x rays will also illuminate the experiment. "The hemispherical target will allow us to experiment with the correct geometry for the first time," says Hansen.

NIF will also simulate the dynamics of supernova remnants, which produce glowing filamentary structures that can be observed for centuries. Scientists speculate that supernova remnants generate most of the cosmic rays that irradiate Earth. Laboratory experiments will help researchers to better understand the mechanisms occurring in remnants and to verify the accuracy of computational models developed to interpret supernova behavior.

targets, and diagnostics on other facilities, such as Jupiter, OMEGA, the Vulcan laser in the United Kingdom, and the Ligne d'Intégration Laser in France.

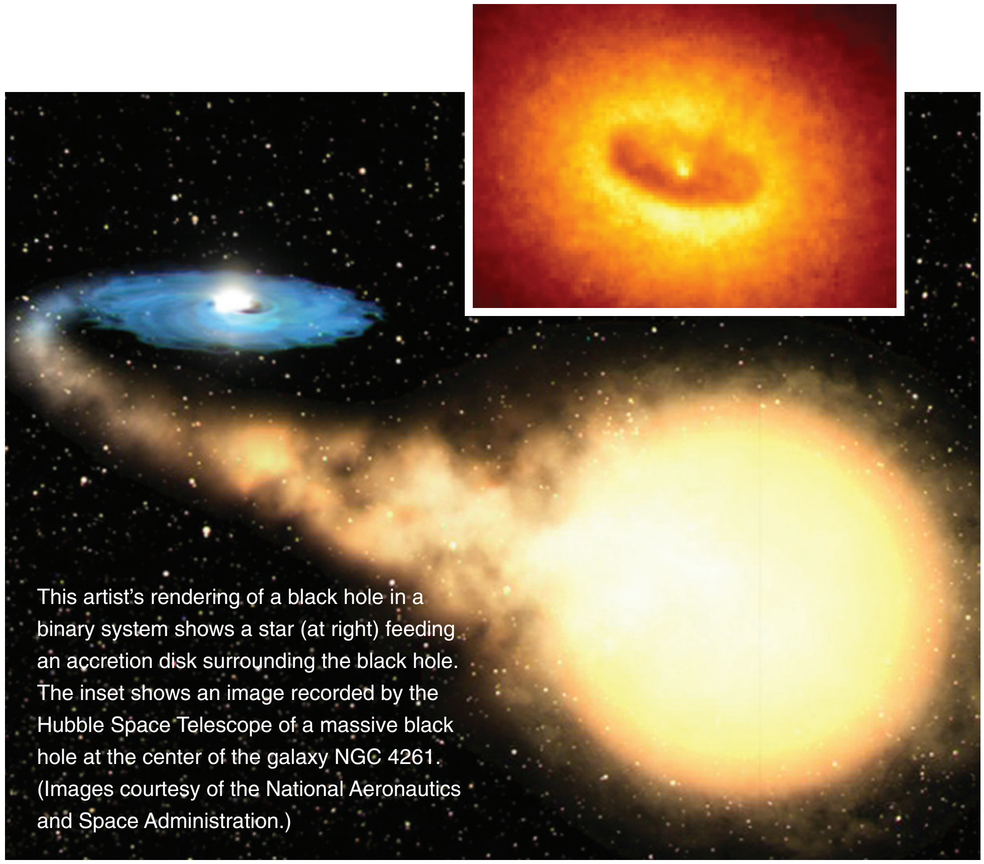
Remington points to long-standing collaboration between Livermore laser scientists and university faculty. For example, the Laboratory established a NIF Professorship Program at UCLA to foster academic partnerships and selected Niemann to hold the first professorship. Several of Niemann's graduate students are conducting research at the Jupiter Laser Facility.

### Experiment Requirements Differ

Each NIF experimental series will require different laser parameters such as wavelength, energy, and pulse duration as well as beam configurations, targets (see the article on p. 12), and diagnostic instruments. By taking advantage of the facility's experimental flexibility, teams can create a variety of physical environments. Densities can range from one-millionth the density of air to 10 times that at the core of the Sun. Temperatures can be varied from cryogenic levels (tens of kelvins) up to the core of a carbon-burning star (a billion kelvins), and pressures can be increased up to 100 terapascals. The phenomena studied will occur in fleetingly short intervals ranging from more than 1 picosecond ($10^{-12}$ second) to fractions of a microsecond ($10^{-6}$ second).

NIF is designed to demonstrate ignition—a burst of fusion reactions in which more energy is liberated than is input. Ignition will generate a burst of about $10^{19}$ neutrons in 100 picoseconds, which corresponds to a flux of up to $10^{33}$ neutrons per square centimeter per second, a rate at which excited-state nuclear reactions may occur. These reactions may allow scientists to study aspects of heavy-element nucleosynthesis—the process that forms elements whose nuclei are more massive than iron. (See the highlight on p. 22.)

Many science experiments will not require all 192 beams operating at maximum energy. In some configurations, groups of laser beams will irradiate a metal plate placed behind the experimental package. This plate, called a backlighter, will produce a short burst of energetic x rays to probe fine details in a fleeting moment. Other diagnostics will precisely record temporal, spatial, and spectral characteristics.



This artist's rendering of a black hole in a binary system shows a star (at right) feeding an accretion disk surrounding the black hole. The inset shows an image recorded by the Hubble Space Telescope of a massive black hole at the center of the galaxy NGC 4261. (Images courtesy of the National Aeronautics and Space Administration.)

Scientists will have the flexibility required to probe plasmas—gases containing ions and electrons, the predominant form of matter in the universe. Diagnostics will measure the plasma's electron and ion temperature, charge state, electron density, and flow velocity. NIF experiments will examine the evolution of plasma perturbations at the interface of two materials. They also will investigate stable and unstable, high-Mach-number plasma flow and the transition to turbulence under extreme conditions. In addition, some experiments will study the complex behavior of nonlinear optical phenomena, which can occur when high-intensity beams interact in plasma.

"Multibeam nonlinear optical processes in plasmas are enormously complicated and can result in radiation fields that propagate at new frequencies or in new directions," says Remington. "We need to understand these processes better so we can control them more effectively on NIF."

### Probing a Star's Life Cycle

Scaled NIF experiments will allow researchers to study physics relevant to the life cycle of a star, from its birth in a cold, dense molecular cloud through its explosive death and postmortem evolution. Nuclear fusion heats a star's interior, and radiation emissions cool its surface, or photosphere. The opacity of each layer controls the rate at which heat moves from the core to the surface. In this way, opacity plays a major role in determining a star's evolution, luminosity, dynamics, and stability.

Experiments will mimic stellar plasma to measure the opacities of key elements such as iron and determine how opacity changes with plasma

## Photoionized Plasmas around Accreting Black Holes

One of the most fascinating objects in the universe is a so-called compact object, such as a neutron star or a black hole. Black holes are typically found in the center of a galaxy or in a binary system, associated with another star. So much mass is concentrated in a relatively small area that nothing, not even light, can escape a black hole's gravitational pull.

Supermassive black holes have rotating accretion disks, giant rings of gas and dust that can stretch hundreds of light years across. The disks have a cold outer region and an ultrahot inner region. The inner region feeds matter into the black holes. Although a black hole itself is not visible, the orbiting hot gases closest to it emit powerful x rays. Cooler material farther away emits visible radiation.

Orbiting x-ray satellites trained on black holes have recorded high-resolution spectral signatures of the hot matter as it spirals inward from the accreting disks. Researchers hypothesize that photoionized plasma causes the spectra. Typical collisional plasma is composed of a hot gas of ions and electrons caused by collisions among atoms. In contrast, photoionized plasma is caused by x rays so intense they strip electrons off elements, even in the absence of collisions.

"We believe that much of the gravitational potential energy of the in-falling matter is converted into hot, bright x rays," says Bob Heeter, a plasma physicist at Livermore. "These x rays produce the photoionized plasma we observe around a black hole."

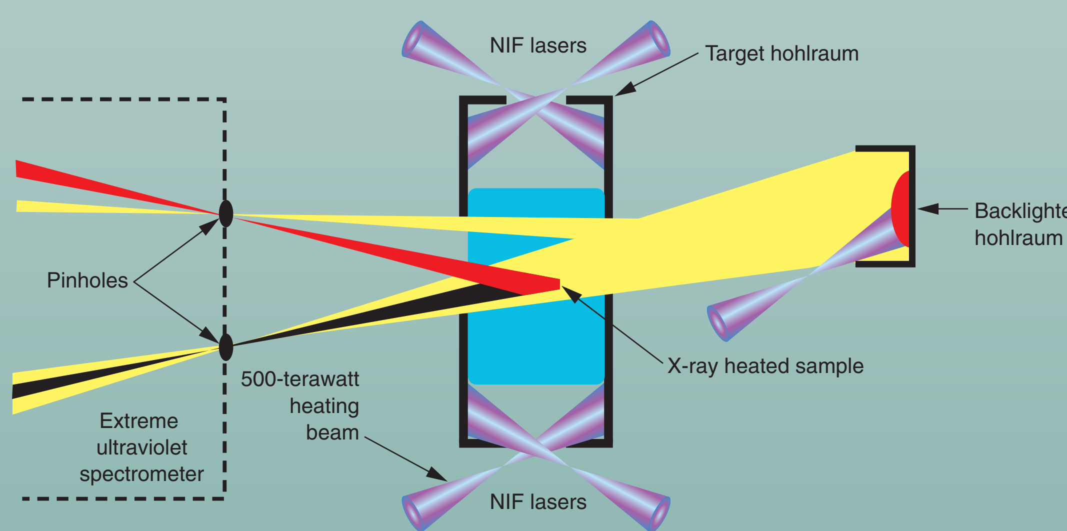
A more complete understanding of x-ray spectra could reveal the temperature, composition, flow velocity, and density of the accretion disks and the physical processes that shape them and form the photoionized plasma. However, researchers must first decipher the complex spectrum of highly ionized iron recorded by x-ray satellites. These spectra contain thousands of spectral lines that differ in frequency, depending on which electrons and how many of them the x rays have stripped from each atom.

Experiments designed for the National Ignition Facility (NIF) will produce the most extreme photoionized plasmas to be studied in a laboratory setting, allowing scientists to better interpret the data recorded by orbiting x-ray observatories. "We'll be able to help define the size, shape, and composition of the accretion disks and calculate how fast the black hole gathers matter," says NIF plasma physicist Bruce Remington. Scientists will compare the spectroscopic results to theoretical calculations and to the data recorded by x-ray satellites.

The NIF experiments will be based on techniques developed by Heeter and other Livermore physicists working with high-energy-density systems such as the Z machine at Sandia National Laboratories in New Mexico and the 60-beam OMEGA laser at the University of Rochester's Laboratory of Laser Energetics. In collaboration with colleagues from Sandia, Queen's University Belfast, Oxford University, and other institutions, Heeter used the Z machine to create photoionized plasmas of iron. However, in these experiments, the densities were higher and plasmas less photoionized than those found in space. "NIF will create intense conditions more like those found in astrophysical systems," says Heeter. The giant laser will generate an x-ray flux about 100 times greater than the Z-generated flux and impinge on iron plasmas at the same or lower density, to more closely approximate the conditions associated with black holes.

In the NIF experiments, a laser-heated gold hohlraum (a cylindrical "can") will enclose a sample of iron encased in plastic foil. The plastic will hold back the expansion of the iron plasma caused by the intense x-ray flux. Laser beams will heat the gold walls to well over 2 million kelvins, creating an intense x-ray flux for about 2 nanoseconds. The experiments will measure x-ray transmission and absorption of the iron to obtain an accurate spectral fingerprint. "Instead of the black hole, we'll use NIF as our x-ray source," says Heeter, "so we can accurately measure the radiation produced by photoionizing iron."

NIF experiments will use hohlraums to heat a sample of iron and spectroscopically diagnose it. The laser beams directed at a gold hohlraum will create intense x-ray fluxes to produce photoionized plasma. Diagnostics will measure x-ray transmission and absorption of the iron plasma.



density and temperature throughout a star's lifetime. For these experiments, researchers plan to simultaneously measure a material's temperature, density, and radiation transmission.

With such experiments, researchers can better understand stellar objects such as Cepheid variables, massive stars whose luminosities pulsate over periods of days to weeks. A remarkable feature of Cepheid variables is that their pulsation periods are proportional to their average luminosities. Astrophysicists have identified about 700 Cepheid stars in the Milky Way Galaxy, including the North Star, Polaris. Pioneering opacity experiments conducted on the Laboratory's Nova laser in the early 1990s and more recently on the Jupiter Facility lasers improved scientific understanding of Cepheid variables. (See *S&TR,* April 1999, pp. 10–17.)

Supernovae mark the death of massive stars by mechanisms not fully understood. The explosions are characterized by strong shocks and turbulent hydrodynamics. To simulate this process in scaled experiments, researchers will use laser beams to shock a hemispheric, multilayered target designed to resemble the different material layers of a supernova. Livermore scientists and colleagues from the University of Michigan and other universities have already made progress in re-creating the turbulent hydrodynamics driven by Rayleigh–Taylor instability, which is also important to weapons studies. NIF will allow researchers to conduct the first detailed three-dimensional experiments of strong-shock-induced Rayleigh–Taylor instability. (See the box on page 8.)

Black holes are one of the most exotic objects in the universe. Understanding the dynamics of matter as it spirals inward toward a black hole is an enormous scientific challenge. NIF will create photoionized plasmas to test models and improve interpretations of x-ray data recorded by space-based observatories of accreting black holes and neutron stars. (See the box at left.)

Astrophysicists are also interested in determining how planets are formed and characterizing their interior structures. NIF experiments will duplicate the physical regimes at the interiors of the planets in our solar system and the more than 200 planets discovered beyond it. (See the highlight on p. 20.) Experimental data on the equation of state and other properties of hydrogen and helium are needed to test models of the interiors of Jupiter and Saturn. Scientists will also use NIF to better understand the interior structures of the giant ice planets Uranus and Neptune.

Another planned experiment will address the properties of dust grains, which control the cooling rate of young galaxies. Dust particles range in size from nanometers to micrometers. Scientists want to determine what mechanisms, such as shock processing and collisions among grains, affect particle size. One approach is to examine how shock waves affect interstellar dust. Researchers also want to study the damage mechanisms that occur when interplanetary dust particles traveling at hypervelocity—tens of kilometers per second—slam into space hardware. Experiments on NIF would launch a strong shock wave through a reservoir of lightweight foam loaded with dust particles on its backside. As the strong shock breaks through the back of this reservoir, dust particles would be accelerated to high velocities and impact surrogate space hardware or be captured in aerogel.

### Future Frontiers

"A lot of very bright people will be using NIF," says Boyd. "Over the next few years, we will see many new ideas for doing science on this system. The best are likely yet to emerge."

Correll notes that NIF represents an important new tool for HED science. "Three nominal steps are required to conduct great experimental science: build a new tool, create a new controlled environment, and produce new insight from experimental data," says Correll. "NIF achieved these steps during the Early Light campaign. When all 192 beams are available, researchers will have the experimental capabilities to conduct discovery-class science."

The new facility is sure to advance a host of physical and material science disciplines, says Remington. As a result, when astronomers point their telescopes to the sky or interpret data from space-based observatories, they will know with much greater certainty what they are seeing and sensing.

*—Arnie Heller*

**Key Words:** backlighter, black hole, Cepheid variable, equation of state, high-energy-density (HED) physics, hohlraum, hydrodynamic instability, ignition, Institute for Laser Science and Applications (ILSA), Jupiter Laser Facility, National Ignition Facility (NIF) Early Light campaign, OMEGA laser, photoionized plasma, Rayleigh–Taylor instability, supernova, Z machine.

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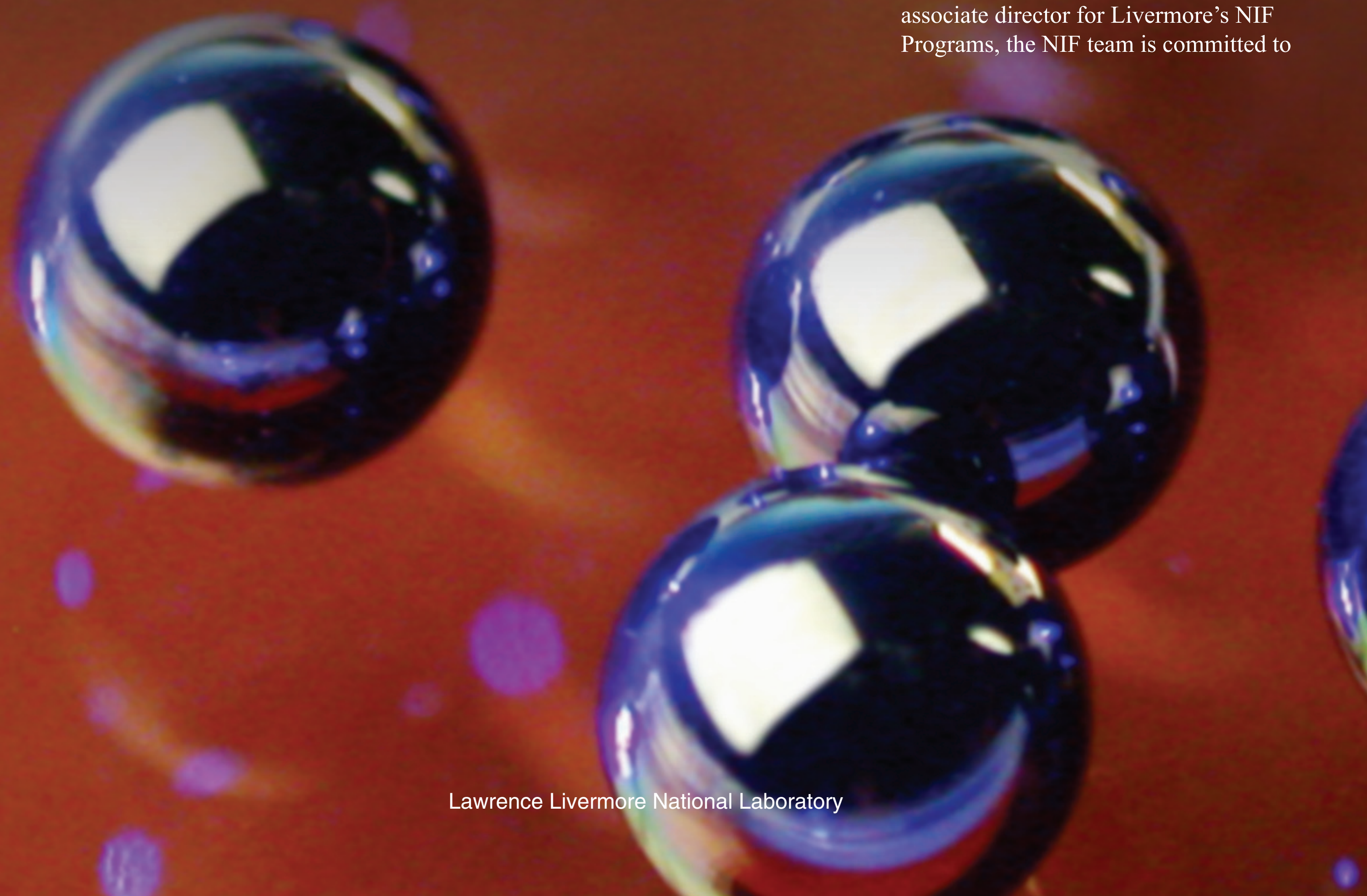
# Meeting the Target Challenge

***Experiments on the National Ignition Facility require innovative targets precisely centered inside the laser's target chamber.***

THE National Ignition Facility (NIF) is a one-of-a-kind scientific laboratory, able to create the temperatures, pressures, and densities of an exploding nuclear weapon or the interior of a large planet such as Saturn. Scientists from around the world will soon put the powerful laser to work in the "X Games" of science, examining physical interactions that were previously impossible to replicate. (See the article on p. 4.)

One such "game" will tackle a scientific grand challenge: demonstrating thermonuclear ignition and gain on a laboratory scale. According to Ed Moses, associate director for Livermore's NIF Programs, the NIF team is committed to



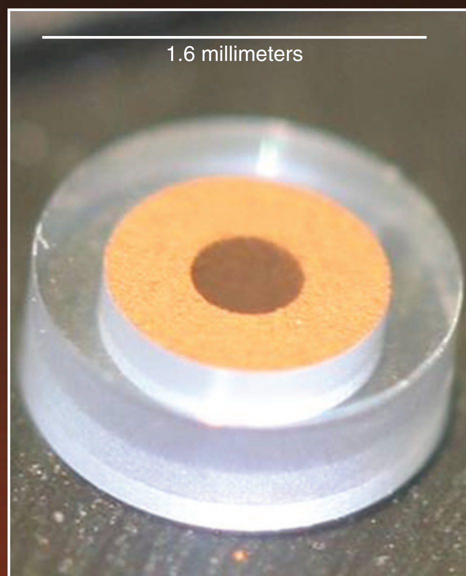
a credible attempt at inertial confinement fusion (ICF) by 2010. This effort is funded by the Department of Energy's National Ignition Campaign, whose goal is to transition NIF into a highly flexible high-energy-density science facility by 2013.

Experiments are also planned to assess the reliability of the nation's nuclear weapons stockpile in support of the National Nuclear Security Administration's Stockpile Stewardship Program. In addition, scientists will use the 192-beam laser to explore basic science research in an array of fields from radiation transport to materials dynamics, hydrodynamics, astrophysics, and nuclear physics.

All of these experiments have one common requirement: a miniscule target, precisely centered in the target chamber. Creating a NIF target is a complex interplay among target designers, materials scientists, and engineers. The designers understand the goals for each experiment and must establish target specifications accordingly. NIF targets are typically only a few millimeters in size, and they must be machined to meet precise requirements, including specifications for density, concentricity, and surface smoothness.

When a new material structure is needed, materials scientists create the essential raw materials. Fabrication engineers then determine whether those materials—some of them never seen before—can be machined and assembled. If the new materials pass muster, components or an entire target will be assembled for an experiment. (See *S&TR*, September 2006, pp. 23–25.)

Throughout the design process, engineers inspect the target materials and components using nondestructive characterization methods to ensure that target specifications are met and that all components are free of defects. Together, this multidisciplinary team takes an experimental target from concept to reality.




Livermore researchers have developed two materials to use in targets for the National Ignition Facility (NIF). The sample shown above is made of extremely low-density gold foam. Below and in the background are hollow capsules made of high-density carbon.

Targets for the ICF experiments are being fine-tuned by a large collaboration that includes scientists and engineers from Lawrence Livermore, Los Alamos, and Sandia national laboratories; the University of Rochester's Laboratory for Laser Energetics; and General Atomics in San Diego. This team is perfecting the target materials and methods to fabricate them. The team also is advancing laser-driver performance, designing new targets, and developing experimental characterization and diagnostic techniques. Jeff Atherton, NIF's deputy associate director for science and technology, leads the ICF target fabrication and materials team, which is using a target design by John Lindl, Steve Haan, Brian MacGowan, and their team of physicists in the Laboratory's Defense and Nuclear Technologies Directorate.

Another project team is synthesizing new materials and inventing fabrication techniques for different kinds of targets. Some of these will be used in fusion experiments to be conducted after the laser achieves ignition. Others will be needed for experiments to advance stockpile stewardship and basic science. Materials scientists and engineers from Livermore's Nanoscale Synthesis and Characterization Laboratory (NSCL), under the direction of scientist Alex Hamza, perform this work as part of a strategic initiative funded by the Laboratory Directed Research and Development Program. (See the box on p. 14.) Nanoscale materials developed

The polished beryllium capsule designed for inertial confinement fusion experiments is 2 millimeters in diameter. The 10-micrometer fill tube attached to the top of the capsule is barely visible.

for NIF experiments include high-density carbon, very low-density copper and gold foams, and graded-density foams.

Manufacturing requirements for all NIF targets are extremely rigid. Components must be machined to within an accuracy of 1 micrometer, or one-millionth of a meter. Joints can be no larger than 100 nanometers, which is just 1/1,000th the width of a human hair. In addition, the extreme temperatures and pressures the targets will encounter during experiments make the results highly susceptible to imperfections in fabrication. Thus, the margin of error for target assembly, which varies by component, is strict.

New tools to image and characterize a material allow scientists to quantify its performance and determine how to improve its fabrication techniques. Computer simulations and experiments conducted at supporting facilities, such as Livermore's Center for Nondestructive Evaluation and the OMEGA laser at the University of Rochester's Laboratory for Laser Energetics, also help researchers refine target designs and improve characterization and diagnostic capabilities.

## The Demands of ICF

"The requirements for ignition targets are especially daunting," says Atherton. The current design for the ICF target is a copper-doped beryllium capsule with a smooth, solid layer of the hydrogen isotopes deuterium and tritium (D-T) on its inner surface. The radially tailored capsule fits inside a 9-millimeter-high by 5-millimeter-wide hohlraum cylinder made of a material with a high atomic number, such as gold.

When NIF's laser beams impinge on the hohlraum's inner cavity, laser energy is converted to x-ray energy. These x rays bathe the capsule and ablate its outer layer. Conservation of momentum requires that the remaining material implode. Compressing the D-T fuel to extraordinarily high temperature, pressure, and density ignites a burning hydrogen plasma.

"The beryllium capsule must have a precise spherical shape for NIF to achieve ignition," says Atherton. The capsule's outer surface must be smooth to within 1 nanometer—an unprecedented requirement for surface roughness—and the thickness and opacity of the copper-doped layers must be carefully controlled. A hole less than 5 micrometers in diameter is drilled through the 150-micrometer-thick beryllium layer so the capsule can be filled with D-T gas. Simulations indicate that a fill hole this size will have only a small effect on the capsule's implosion.

Another challenge is ensuring the symmetry of the implosion. Experiments will require the target capsule to be placed within 8 micrometers of the center of the hohlraum, which is only 1 centimeter in diameter. Within 30 hours after the D-T gas is introduced, it is frozen on the capsule's inner surface, producing a smooth layer with a roughness of less than 1 micrometer.

## Capsule Collaborators

To achieve the daunting specifications for ICF targets, Livermore researchers are working closely with scientists at other

### The Nanoscale Synthesis and Characterization Laboratory

Lawrence Livermore established the Nanoscale Synthesis and Characterization Laboratory (NSCL) in 2004 to advance interdisciplinary research and development opportunities in nanoscience and nanotechnology in support of the Laboratory's national security mission. NSCL brings together experts from Livermore's Chemistry, Materials, and Life Sciences (CMLS) and Engineering directorates. It also fosters collaborations with researchers from other institutions. Alex Hamza of CMLS leads NSCL, and the deputy director is Don Lesuer from Engineering.

NSCL research focuses on the change in behavior that may occur when the size of a material's property-controlling structure shrinks to a few nanometers. For example, some nanometer-scale materials are extremely strong. NSCL researchers work to apply the unusual properties of nanoscale materials to develop technologies for national security. One important research area is fabricating targets for the National Ignition Facility and other stockpile stewardship experimental platforms.

NSCL's long-term research goal is to thoroughly understand materials at the nanoscale. Researchers want to determine how a material's properties and behavior change at the nanoscale and how best to fabricate nanoscale devices. With this knowledge, scientists can then assemble structures smaller than 100 nanometers and manipulate the materials to optimize their performance. NSCL's research focuses on four science and technology areas: nanoporous materials, advanced nanocrystalline materials, three-dimensional nanofabrication technologies, and nondestructive characterization.

institutions in the U.S. and Europe. For example, Laboratory scientists Steve Letts, Suhas Bhandarkar, and Andrea Hodge are working with General Atomics researchers Abbas Nikroo and Andrew Forsman to develop the beryllium capsules.

Each capsule is made by depositing beryllium on a smooth, perfectly spherical plastic mandrel. As the mandrel is rotated, a 150-micrometer-thick layer of beryllium slowly builds up on its surface. After a capsule is polished, a laser is used to drill a fill hole. An oxidation technique removes the mandrel through the drilled hole, and a 10-micrometer tube is attached to the capsule so it can be filled with D-T gas.

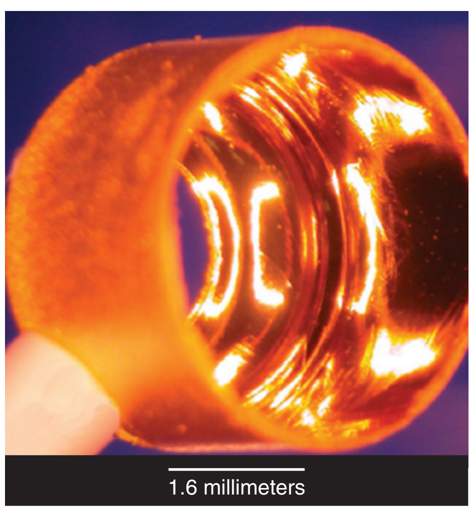
An alternative design to the beryllium capsule uses high-density carbon, which, like beryllium, has a low atomic number. Its higher density (3.5 grams per cubic centimeter) makes it an attractive material for an ICF capsule. Laboratory chemist Juergen Biener is working with researchers at the Fraunhofer Institute for Applied Solid-State Physics in Freiburg, Germany, to implement this design. The Fraunhofer team has developed techniques to deposit high-density carbon films on 2-millimeter silicon mandrels, polish the spheres, and remove the silicon mandrel. The mandrel is removed by etching through the laser-drilled hole where the fill tube will be attached. Livermore is responsible for developing the techniques to fill the shell with fuel.

Fabricating the cylindrical hohlraum is another challenge. Nikroo, Heather Wilkens, and other researchers at General Atomics have developed fabrication techniques that couple as much laser energy to the capsule as possible. Their 7-micrometer-thick hohlraum is made with layers of gold and uranium sputter-deposited on a precision-machined mandrel. (See the figure below left.) After deposition, the mandrel is leached away. Because uranium is highly reactive in the presence of oxygen and water vapor, gold must encapsulate the uranium layers.

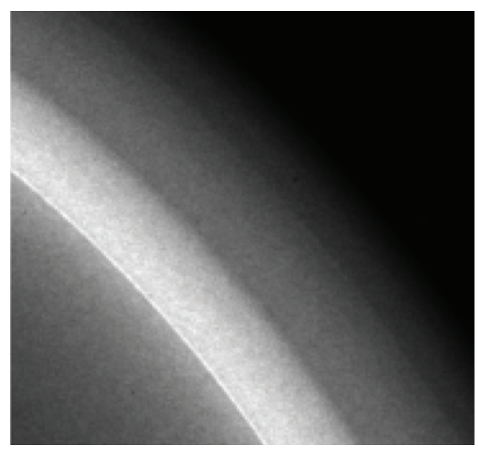
## Fuel Chills Out

Laboratory scientists John Moody, Evan Mapoles, and Bernard Kozioziemski have pioneered procedures to form the frigid layer of D-T fuel inside the fuel capsule. The D-T ice is 1.5 degrees below the triple point of the hydrogen isotope mixture—the temperature at which all three phases of the substance can coexist in equilibrium. Temperature can fluctuate no more than 1 millikelvin—a demanding requirement for accuracy. “Understanding the science of D-T layer formation is critical for the ignition experiments,” says Kozioziemski, “and an extremely exciting endeavor.”

Beta decay of the tritium helps smooth the layer by selectively heating thicker regions and evaporating hydrogen from them. NIF researchers found that the D-T ice can be shaped by precisely controlling heat transfer within the hohlraum, including contributions from thermal convection of helium. Auxiliary heaters located on the hohlraum shape the temperature field within the target to produce a nearly spherical isotherm. To control the ice layer’s surface roughness, the NIF team developed a seeding and cooling protocol. The seeding process forms the initial layer, and cooling reduces its temperature from the triple point. With this protocol, the team achieved a




A hohlraum is the metal case that holds a fuel capsule for NIF experiments. Shown here is one-half of a gold–uranium hohlraum after the mandrel has been removed.



This digital x-radiograph shows a high-density carbon capsule with an inner layer of frozen deuterium–tritium fuel. The capsule’s inner diameter is 2 millimeters. The fuel layer is only 50 micrometers thick, and its surface roughness is a mere 0.5 micrometer.

roughness of about 0.5 micrometer (root mean square) at the interface where solid D-T meets D-T gas.

Livermore engineers Beth Dzenitis and Jeff Klingmann are developing procedures to mount the capsules and control the cryogenic temperature. For this operation, the capsule is “tented” between polymer sheets held in place by the two sides of the hohlraum. A thermomechanical package encases the hohlraum to control the position and temperature of the hohlraum–capsule assembly.

The thermomechanical package is a modular design with a precisely fabricated aluminum structure on each end. A band in the middle of the package has cutouts to accommodate the shot diagnostics. Silicon “arms” attached to each end of the package conduct heat from the hohlraum. These lithographically etched support arms create a heat-transfer path that ensures temperature uniformity in the target. In addition, a flexure coupling between the silicon arms and the aluminum structure accommodates differential thermal contraction.

With the thermomechanical package, the target assembly can maintain its position to within 2 micrometers, and at 18 to 20 kelvins, temperature fluctuations are limited, as required, to 1 millikelvin. “This is a novel approach to target engineering,” says Dzenitis, “designing both for manufacturability and reproducibility.”

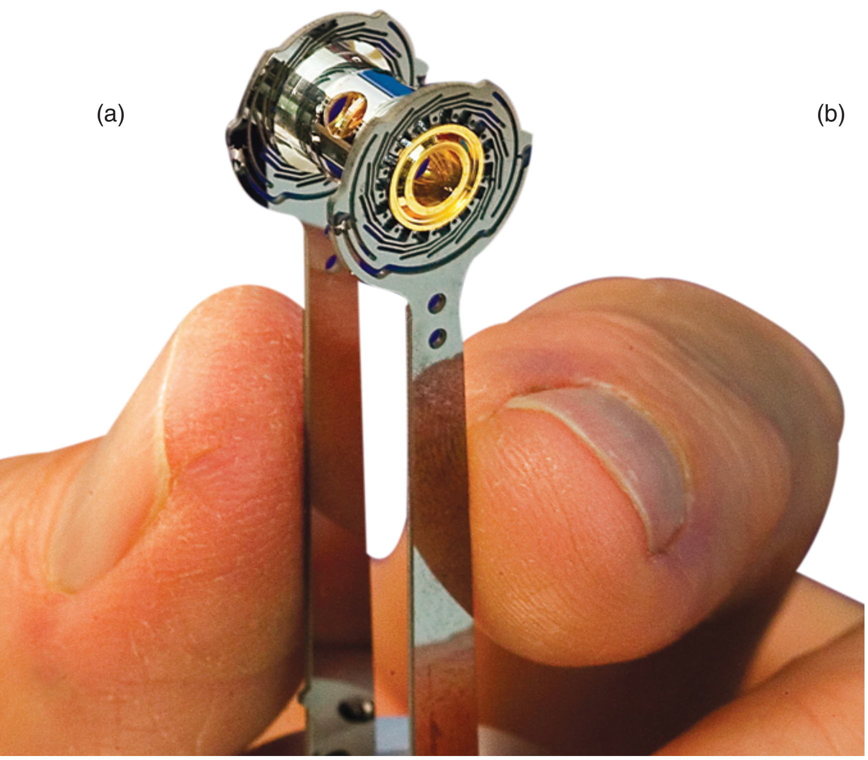
Laboratory researcher Terry Malsbury leads the NIF team responsible for developing the cryogenic target-positioning system. This system integrates the ICF target with a cryogenic layering and characterization station and a target positioner attached to NIF’s target chamber. The system includes a positioning boom to center the target in the chamber. An ignition-target inserter cryostat attached to the positioner cools the target and the D-T fuel to meet temperature and uniformity requirements. The layering and characterization station can image the D-T fuel layer in three directions within a few minutes.

## Targets in a Lather

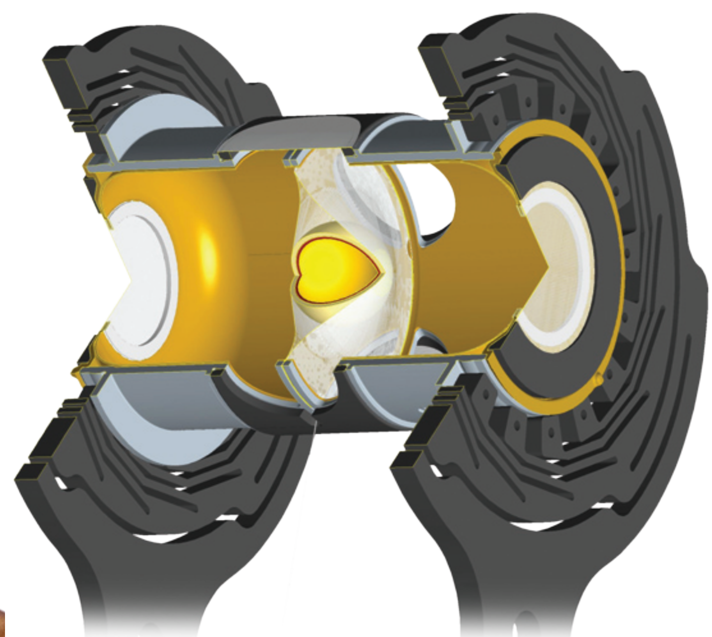
Livermore scientists are experimenting with a variety of extremely low-density foams. For example, copper foams will be used to explore high-energy-density science and advanced fusion concepts, and nanoporous gold foams are being developed for hohlraums.

Octavio Cervantes, a materials scientist in the Chemistry, Materials, and Life Sciences Directorate, has upgraded a process designed to build copper foam with pores smaller than 1 micrometer in diameter. To make the foam, Cervantes

(a)



(b)



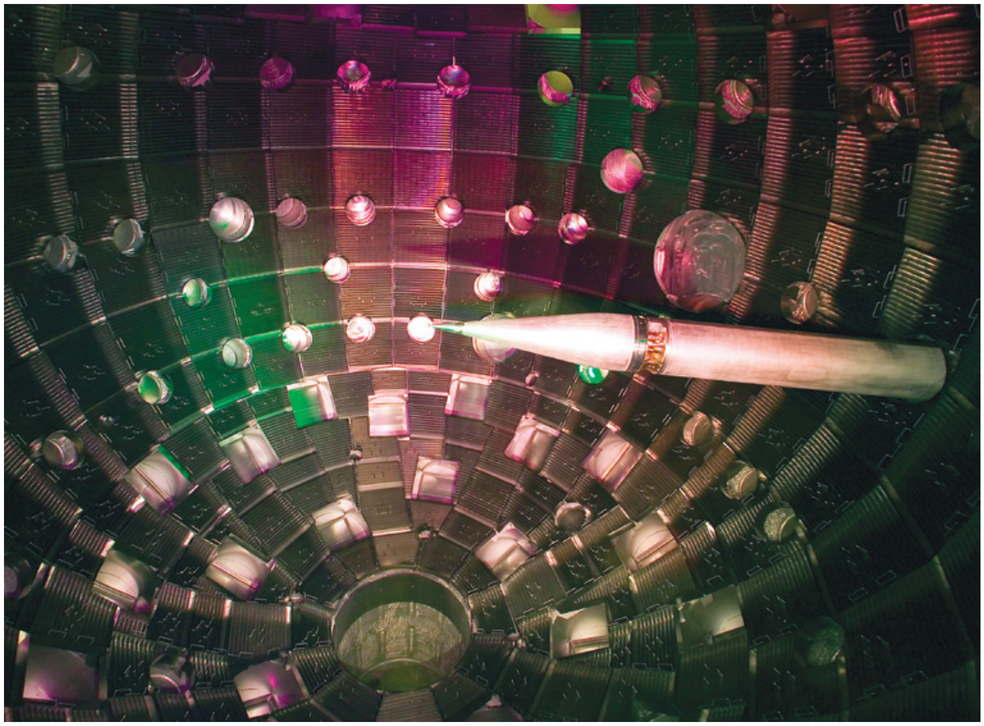
(a) The thermomechanical package for the hohlraum–capsule assembly has a 2-millimeter-diameter capsule in the center.
(b) A cutaway rendering of the package shows the tenting of the capsule and the silicon support arms.

pours a solution of water, copper nanoparticles, and polystyrene spheres onto a water-absorbing medium. As the water is absorbed, the copper particles are deposited onto the medium's surface, forming a uniform monolith. Annealing the monolith burns off the polystyrene, leaving behind the copper foam.

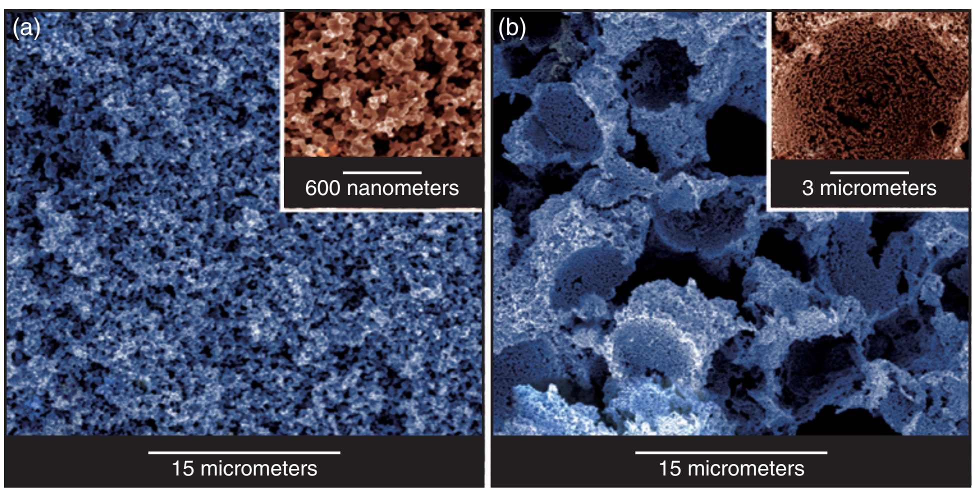
Polystyrene spheres 1 micrometer in diameter produced foam with a relative density of 15 percent. A mixture with spheres between 0.5 and 1 micrometer could potentially decrease the foam's density to 10 percent, or 890 milligrams per cubic centimeter. The foam is extremely light yet strong enough to be machined into simple structures such as small disks and hollow cylinders. Researchers at the Center for Nondestructive Characterization are developing laser-based ultrasonic methods to measure the foam's mechanical properties.

The path to designing nanoporous gold foams has been more circuitous. Livermore chemist Greg Nyce tried coating polystyrene beads with gold and casting them into a monolith mold in a process similar to that used by Cervantes. When the mold was heated, however, some of the hollow gold spheres contracted, which increased the gold's relative density to 20 percent instead of the 1 to 2 percent required for the NIF targets.

One method proposed to solve this problem is dealloying. In this process, polystyrene beads are coated first with a layer of gold and then with a layer of silver. Heating the monolithic structure to more than 670 kelvins removes the beads and produces hollow silver-and-gold shells. The shells are then exposed to nitric acid to remove the silver, leaving a shell of nanoporous gold. The dealloyed foams have a relative density of 2 percent, or 400 milligrams per cubic centimeter—a significant reduction for gold particles, which at full density weigh 19.3 grams per cubic centimeter.



Before each NIF experiment, a positioner precisely centers the miniscule target inside the target chamber. In inertial confinement fusion experiments, the target-positioning system will integrate the target with a cryogenic layering and characterization station and a target positioner.




Scanning electron microscope images show how polystyrene beads in copper foams create empty space, which reduces a material's density. (a) A foam with no beads has a relative density of 25 percent. (b) Using beads 10 micrometers in diameter reduces the foam's relative density to 10 percent. Insets show micrographs at high resolutions.

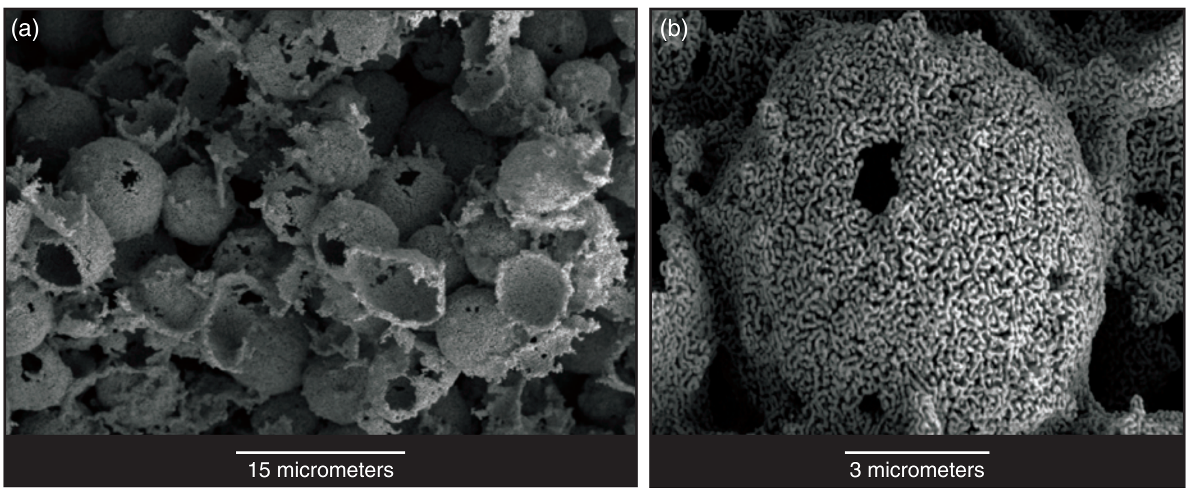
"The product is very fragile," says Nyce, "but it can be machined." Nyce recently received a Nano 50 Award from *Nanotech Briefs* for the gold foams, which are fabricated with 500-nanometer shells.

### Varying Foam Densities

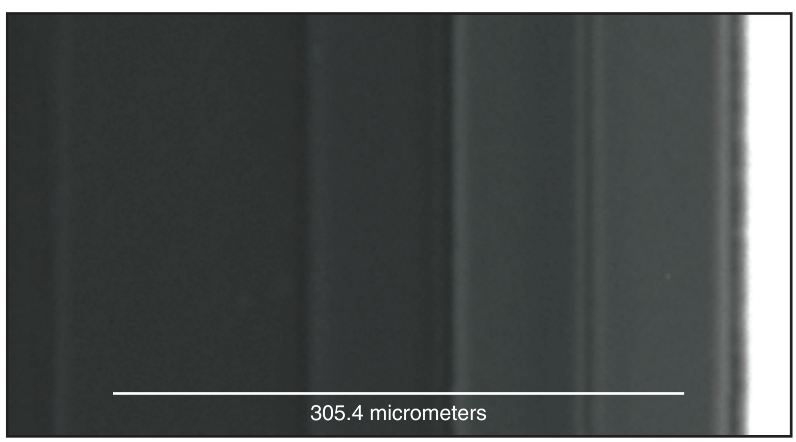
Another target design uses graded-density foams. In a high-energy-density experiment, a laser such as NIF can slam into a graded-density target without creating a shock, allowing researchers to determine a material's strength under high pressure and density but low temperature. (See *S&TR*, March 2007, pp. 23–25.) These foams can also be layered with varying density gradients to tailor the shock delivered to the material being studied. Target designers want graded-density foams about 0.5 millimeter thick, with the highest density material tapering off to zero density. (See the bottom figure below.)

To develop these novel materials, a team of chemists led by Joe Satcher is experimenting with carbon aerogels of various densities. For this project, Livermore engineer George Langstaff and machinists on the target fabrication team produce aerogel slabs each about 50 micrometers thick. Satcher's team then bonds the slabs together using a silica aerogel "glue" that is barely denser than air. This method can produce stepped-gradient structures up to 0.5 millimeter thick, with density gradients tailored to meet experimental requirements.

Livermore engineer Robin Miles and her team have had some success making graded-density foams with proximity nanopatterning, a technique pioneered by John Rogers at the University of Illinois.

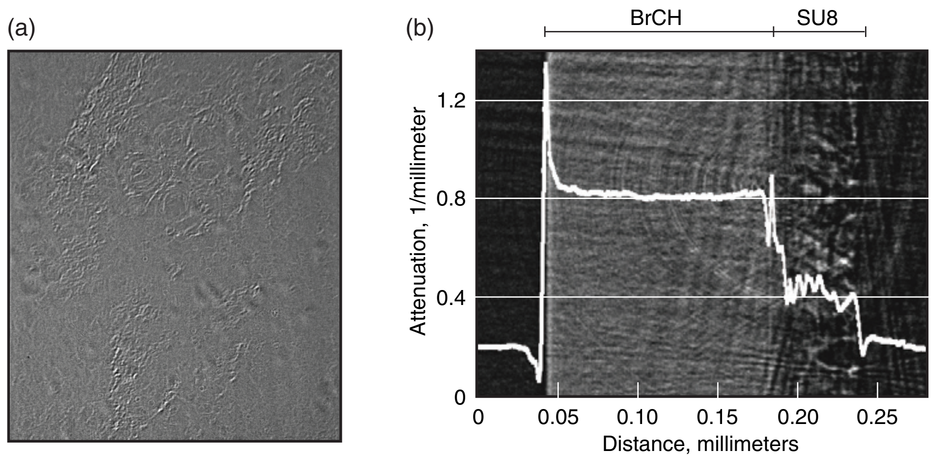



Scanning electron micrographs of porous gold (a) before and (b) after dealloying show how this process changes a material's density.




This micrograph shows a graded-density structure made of carbon aerogel bonded with a silica aerogel "glue" that is barely denser than air.

With this technique, they can design a structure so that density decreases continuously from end to end. Miles's team tailored a graded-density foam that absorbs light in SU8 while imprinting a nanostructure from an elastomeric mask. This structure grades from full density to 5 percent relative density. (See the figure at right.) The films developed to date are 80 to 100 micrometers thick. Says Miles, "Scaling up to a thickness of 500 micrometers is the next challenge."




(a) A digital radiograph provides a planar view through a graded-density target made of a brominated polystyrene (BrCH) substrate with 60 layers of a photopolymer (SU8). The density of SU8 changes from full density to 5 percent relative density with each 1-micrometer layer. (b) A computed tomography cross section of the target with a profile overlay shows the layer-by-layer decrease in density.

## Final Evaluation

Nondestructive characterization—a technique for inspecting materials without damaging them—is a key tool for evaluating the complex, fragile materials used in NIF targets. The resulting data allow researchers to predict a material's performance, examine its structure, and model its behavior. Livermore scientist Harry Martz and his team are responsible for developing the nondestructive techniques needed to evaluate the NIF targets. Martz is also working with fabrication engineer Matthew Bono to design methods for handling and holding the tiny, delicate components.

Peering inside optically opaque materials requires penetrating x rays, acoustic waves, or particles. Livermore's x-ray computed tomography system images materials with a resolution of less than 1 micrometer over a 1-millimeter field of view. Another evaluation technique is synchrotron radiation, which produces x-ray microdiffraction images showing a material's structure.

Koziozlemski, Martz, and others used phase-contrast enhanced x-ray imaging to examine the D-T layer in a beryllium fuel capsule. (See the bottom right figure on p. 15.) Absorption x-ray imaging cannot distinguish the layers clearly enough because the capsule materials have such a wide range in opacity—the D-T fuel is 10,000 times less opaque than the shell. However, the phase-contrast technique produced the first images of the solid D-T fuel layer inside a copper-doped beryllium shell. Precision radiography can also detect opacity fluctuations buried in the beryllium shell.

"Graded-density materials are especially difficult to study and interpret," says Martz. One characterization method tried by his team combines digital x-radiography and computed tomography. Distortions called phase effects at material boundaries make it challenging to measure the gradient. Computer simulations indicate that acoustic microscopy may be a better diagnostic method. When surface acoustic waves propagate through a multilayered material, the pattern of propagation across the surface varies with density. "Gigahertz frequencies can yield micrometer spatial resolution in millimeter-size samples," says Martz, "which is the level of detail we need."

## Targets for Science

Lawrence Livermore has a long history of developing new materials, fabrication techniques, and characterization and diagnostic methods to address the important national problems it is asked to solve. From miniaturizing nuclear weapons in the late 1950s to proving fusion ignition on a laboratory scale five decades later, Livermore's can-do attitude consistently meets with success.

Livermore researchers are already using the expertise developed in designing NIF targets to support the Department of Energy's high-energy-density science mission. The experience gained from that work will no doubt be applied in some future, as yet unknown scientific endeavor.

*—Katie Walter*

**Key Words:** beryllium capsule, Center for Nondestructive Characterization, cryogenics, high-density carbon, ignition target, inertial confinement fusion (ICF), metallic foam, nanoporous material, Nanoscale Synthesis and Characterization Laboratory (NSCL), National Ignition Facility (NIF).

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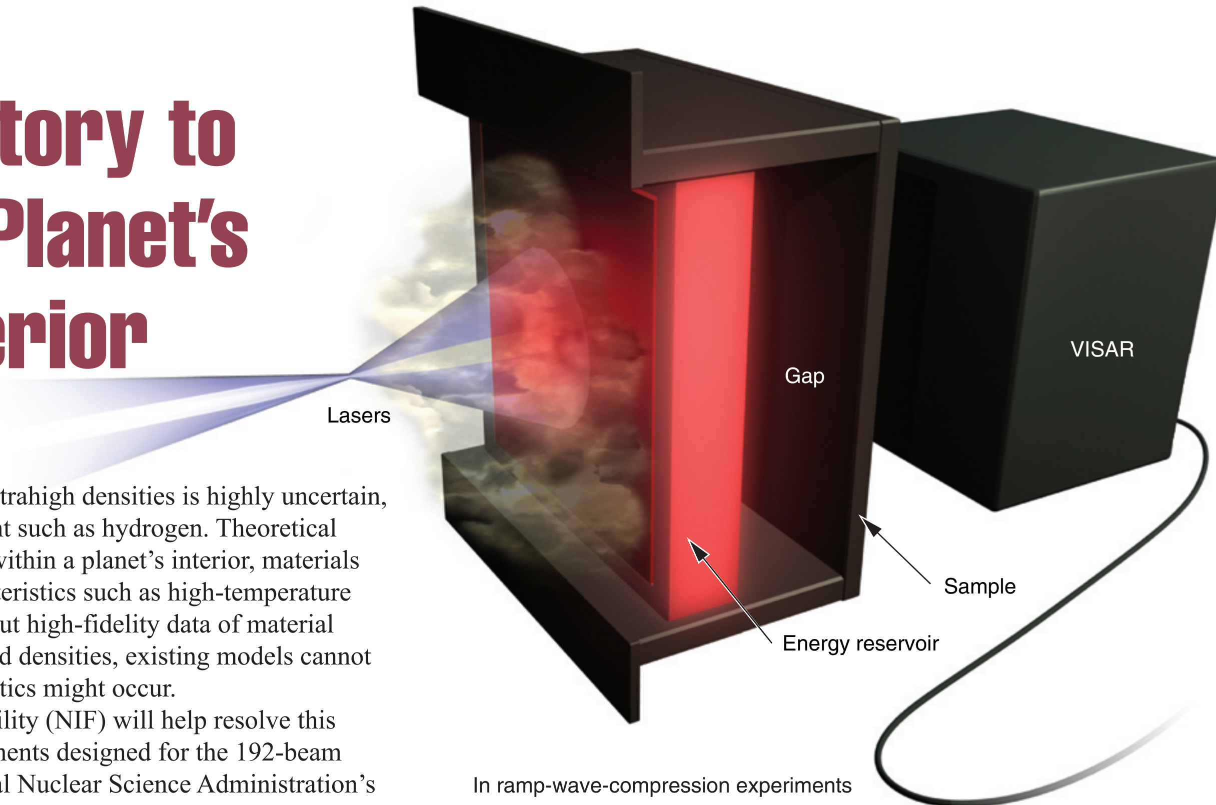
# A Laboratory to Probe a Planet's Deep Interior




In ramp-wave-compression experiments planned for the National Ignition Facility (NIF), a laser pulse focuses onto an energy reservoir and condenses the material, creating a plasma piston that compresses the test sample. A diagnostic called VISAR (Velocity Interferometer System for Any Reflector) measures the velocity of multiple sample interfaces as a function of time.

MATERIAL behavior at ultrahigh densities is highly uncertain, even for a simple element such as hydrogen. Theoretical research indicates that deep within a planet's interior, materials could exhibit unusual characteristics such as high-temperature superconductivity. Yet, without high-fidelity data of material behavior at high pressures and densities, existing models cannot predict why those characteristics might occur.

The National Ignition Facility (NIF) will help resolve this problem. Most of the experiments designed for the 192-beam laser will support the National Nuclear Science Administration's Stockpile Stewardship Program. In addition, a portion of NIF shots will explore basic science research in various fields, including astrophysics. These experiments will allow researchers to characterize materials at the extreme densities and pressures typical of the deep interiors of solar and extrasolar giant planets.

### Material Behavior Deep within a Planet

The first shock-physics experiments planned for NIF will explore planet formation and structure. For this research, Livermore physicists Peter Celliers, Jon Eggert, Damien Hicks, Ray Smith, and Gilbert Collins in the Physics and Advanced Technologies Directorate are collaborating with Raymond Jeanloz from the University of California at Berkeley, Thomas Duffy from Princeton University, Russell Hemley from the Carnegie Institution, Yogendra Gupta from Washington State University, and Paul Loubeyre from Université Pierre et Marie Curie in France as well as with colleagues from other Laboratory directorates. The researchers plan to study the phase state (fluid or solid) that elemental hydrogen assumes when subjected to extreme heat and pressure. "To better understand the evolution, structure, and internal chemistry of solar and extrasolar planets, we must accurately predict the properties of hydrogen at extreme density and temperature," says Celliers. "NIF will replicate the conditions needed to characterize this element in a laboratory setting."

Planets in the solar system exhibit matter in various ordinary and exotic states. For example, on Earth, when hydrogen and oxygen combine to form water, the compound can take the form of a gas (steam), a fluid (water), or a solid (ice). Water can also exist in the exotic realm. If extreme changes in pressure or temperature occur, the molecular bonds between hydrogen and oxygen can stretch, break, and reconnect in unexpected forms that do not resemble the ordinary states of steam, water, and ice.

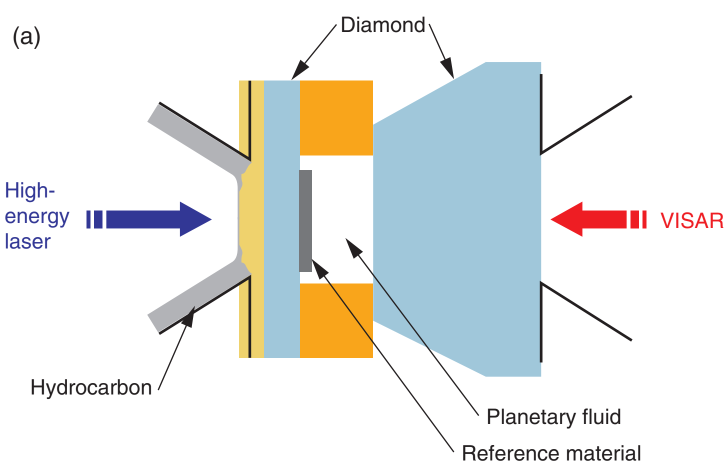
This transitional behavior is difficult to observe and challenging to create or predict. The same is true with other exotic states of matter such as metallic hydrogen or metallized diamond, which have been demonstrated in quantum molecular dynamics simulations and may occur naturally in a giant planet such as Jupiter. Results from experiments at NIF can help researchers better model and predict the changes occurring in these materials.

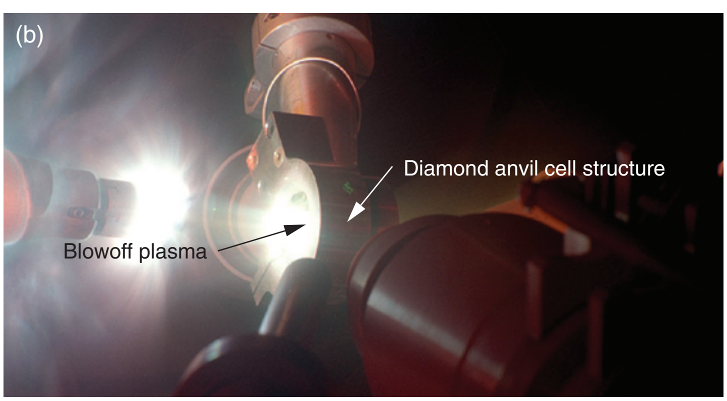
### Squeezing Matter to Extremes

To replicate these phase states, the Livermore team plans to stage a series of ramp-wave-compression (RWC) experiments. RWC experiments increase the pressure applied to a sample without inducing a shock wave. (See *S&TR*, March 2007, pp. 23–25.) By precisely shaping the pressure pulse, the team will be able to compress test materials up to 2,500 gigapascals, or $2.5 \times 10^{12}$ pascals. By comparison, air pressure at sea level is 100,000 pascals.

For example, in one experimental design, laser beams will heat a carbon-based energy reservoir, which will then unload its energy in the form of a plasma piston that shocklessly compresses samples of differing thicknesses. The research team will then measure each sample's velocity profile and use those data to determine the material's equation of state. Equations of state express the thermodynamic relationship between pressure, temperature, and volume for a given sample and are essential for generating reliable computational models of material behavior. With the RWC technique, a sample will remain relatively cool and solid with nearly constant entropy, even under very high pressure.

"The RWC experiments will allow us to inspect condensed matter in states that are similar to those occurring in the deep interiors of planets," says Collins. "These experiments will require the full energy of NIF. The data acquired will help us accurately model the structure and evolution of the giant planets."




(a) The diamond anvil cell experiments at NIF will apply a strong laser-produced shock to a precompressed sample of planetary fluid. A VISAR diagnostic will record the shock velocity of the sample and the reference material, which researchers will use to extract the density and pressure of the shocked precompressed sample. (b) A time-integrated photograph from an experiment on the OMEGA laser shows a strong shock applied to a precompressed sample of helium held between two diamonds.

## Shock-Compressing a Precompressed Fluid

Another technique for examining materials under extreme densities is to launch strong shocks in planetlike fluids that are already compressed to an initial high state of pressure and density. This precompressed state is achieved in a diamond anvil cell (DAC). Precompression allows researchers to tune the sample's initial density and thus the final states that can be achieved with strong shocks. "By applying a strong shock to a precompressed sample," says Collins, "we can re-create the deep interior states of solar and extrasolar giant planets."

In a DAC, a support structure holds two diamonds that squeeze a planetary fluid sample contained inside a washer. The diamond on the drive side of the target is thin, so the laser-produced shock remains strong and planar as it transits through the diamond. The diamond's thickness determines the initial precompressed pressure. Because NIF will have outstanding pulse-shaping capability and so much energy, the diamond on the drive side can be much larger than those used in experiments on lower-energy facilities. The sample's initial density and pressure can thus be higher.

To prevent the sample from being heated before the shock, the Livermore team will use a preheat barrier to absorb the high-energy x rays. An ultrafast diagnostic called VISAR (Velocity Interferometer System for Any Reflector) works like a speedometer for shocks, recording the shock velocity of the sample and reference material. "From these data, we will extract the density and pressure of the shocked precompressed sample," says Collins. "We will also use the optical emission from the shock front to measure shock temperature."

## Benefits for Basic and Applied Science

In addition to answering questions about planet formation and structure, results from these experiments will benefit the Laboratory's national security missions. The extreme conditions in a planet's deep interior also occur during a nuclear weapon detonation, so data on material behavior at ultrahigh temperatures and pressures can be applied to Livermore's stockpile stewardship research. Examining the behavior of ultradense matter will also help scientists better understand how matter compresses and heats on the way to thermonuclear ignition and burn.

By replicating these extreme environments in NIF experiments, scientists will have the tools needed to model the exotic worlds they can never visit.

*—Alane L. Alchorn*

**Key Words:** astrophysics, diamond anvil cell (DAC), equation of state, National Ignition Facility (NIF), phase transition, plasma piston, ramp-wave-compression (RWC) experiment.

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# A Closer Look at Nucleosynthesis

ACCORDING to the Committee on High Energy Density Plasma Physics at the National Academy of Sciences, one of the great challenges facing scientists today is understanding how elements form. This process, called nucleosynthesis, occurs at the extremely high temperatures and pressures found in stars and supernovae—an environment that has been nearly impossible to reproduce in a laboratory setting. When experiments begin on the National Ignition Facility (NIF), scientists will have the tools they need to examine this previously unseen process.

With its 192 laser beams, NIF will generate 2 megajoules of laser energy—enough to create a miniature star. Scientists can use this scaled version of the stellar environment to study how stars create the elements. Livermore researchers are collaborating with colleagues at the University of California at Berkeley, Lawrence Berkeley National Laboratory, the Colorado School of Mines, and Ohio University to prepare for the initial NIF experiments.

## Three Stellar Processes

Apart from hydrogen, helium, and a small amount of lithium, which formed during the first three minutes after the big bang, most of the elements in stars are created in one of three nucleosynthesis reactions. Nuclear fusion creates the elements in a young star. Two neutron-capture reactions, called the slow (s) and rapid (r) processes, kick in as a star ages and dies, forming most of the elements heavier than iron.

In the fusion reaction, nuclei of lightweight elements slam together and fuse, releasing large amounts of energy and generating the nuclei of heavier elements. Lightweight elements, which have the fewest protons, appear near the top of the periodic table. For instance, nuclei of hydrogen—the lightest element, with one proton—can fuse to form helium. Helium nuclei can in turn create carbon. Carbon becomes part of the fuel for producing even heavier elements, such as oxygen.

Because both nuclei carry a positive charge, they cannot fuse unless they overcome the Coulomb repulsion—an electrostatic force that tends to separate them and prevent interaction. "We can demonstrate a similar effect by trying to force two magnets together," says Livermore nuclear physicist Lee Bernstein. "We can feel the magnets repel each other, and the closer we push them, the stronger that force becomes." In the dense interiors of stars, an effect called electron screening reduces the positive charge of two nuclei. Electron screening thus increases the probability that the nuclei will overcome the Coulomb repulsion and fuse to create a new element.

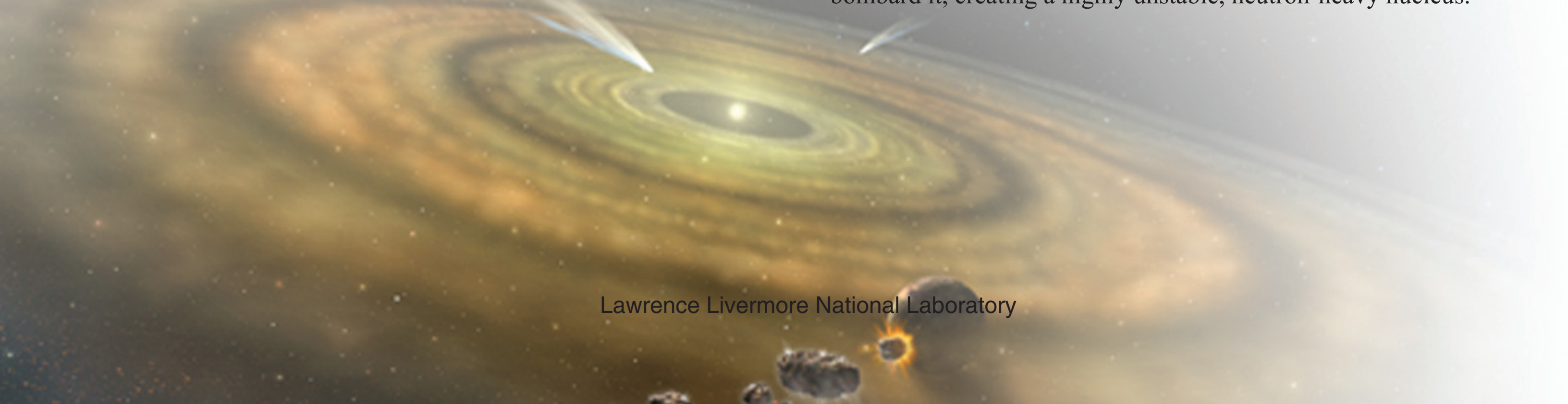
To date, accelerators are the only technology that can duplicate this process. With an accelerator, researchers can bombard a target with a very high-energy pulse of positively charged ions. However, even if an accelerator could be tuned to the low energies relevant to stellar temperatures, the probability of an ion fusing with the nucleus of a target atom is extremely low. The particle fluxes generated by the accelerator would be too low to produce enough reactions to be measured. "Running an accelerator continuously might yield two such reactions in a month," says Livermore physicist Dick Fortner.

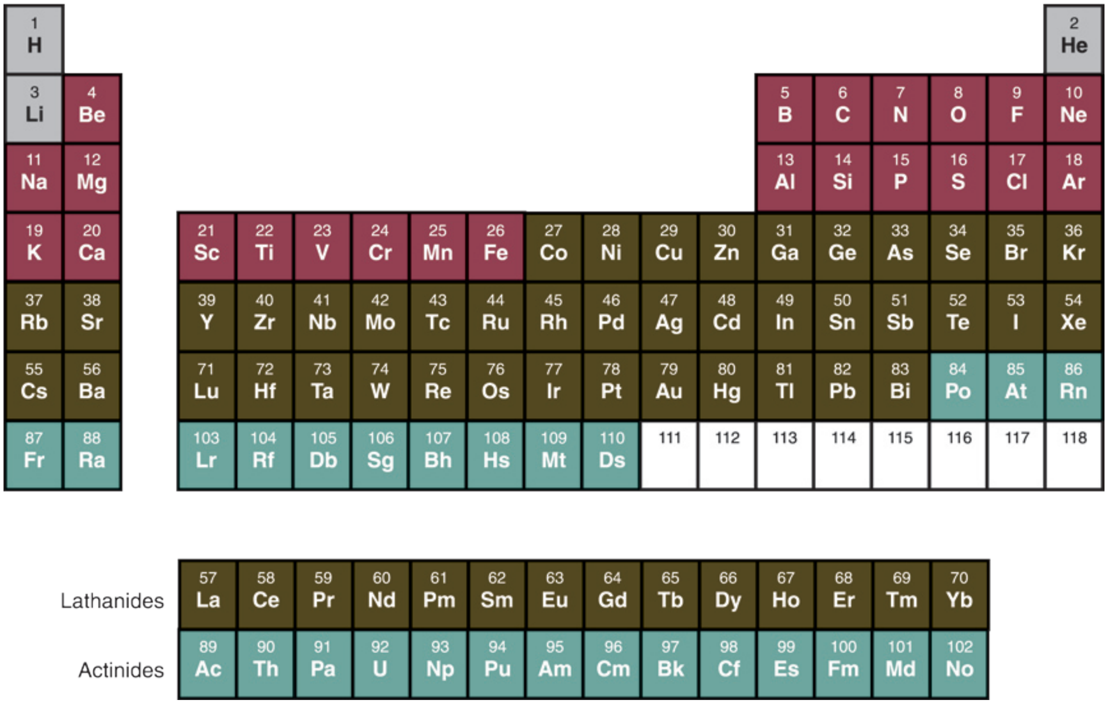
NIF will provide the experimental conditions needed to observe these elusive reactions. It will create a starlike thermal environment with densities between $10^{23}$ and $10^{26}$ atoms per cubic centimeter and temperatures up to 10 kiloelectronvolts. These experiments will use target capsules loaded with a fuel of helium-3 and helium-4. NIF's laser beams will compress the fuel and produce beryllium-7, a critical reaction in stellar hydrogen burning, at a rate that can be measured for the first time. "We estimate that one experiment will produce 300,000 beryllium-7 atoms," says Bernstein.

## From Lightweight to Heavyweight

The s-process occurs at relatively low neutron densities and intermediate stellar temperatures. In this process, a nucleus captures a neutron. The resulting nucleus can be stable, or if it is radioactive, it will decay to a stable form before the next neutron is captured. The s-process accounts for about half of the isotopes of elements heavier than iron. Because the s-process involves stable isotopes with long decay times, scientists can readily examine it in the laboratory. As a result, these physical reactions are well understood.

The r-process, in contrast, occurs only when neutron densities and temperatures are extremely high, such as those in a supernova when a star collapses and explodes. In the r-process, neutrons hit a nucleus, and before the nucleus can decay, even more neutrons bombard it, creating a highly unstable, neutron-heavy nucleus.






The periodic table lists elements according to the number of protons in their nucleus. Thus, it begins with the element that has the fewest protons—hydrogen, with one—and proceeds to the element known to have the most, which currently is element 118, with 118 protons. (See *S&TR*, April 2007, pp. 22–24.) Gray elements formed in the first three minutes of the big bang. Other lightweight elements (burgundy) form in fusion reactions that create heavier elements, which serve as fuel for even heavier elements. Slow neutron capture, called the s-process, occurs in massive stars to form elements beyond iron (brown). Still heavier elements (turquoise) form in explosive environments, such as in a supernova, through a rapid neutron-capture reaction called the r-process.

The number of additional neutrons eventually reaches equilibrium so that their capture and release occur at about the same rate. At this point, when a neutron-capture reaction emits a photon, the photon knocks a neutron from the nucleus. This equilibrium point is typically about 20 neutrons beyond the neutron-rich edge of the stable nuclei.

This equilibrium point occurs when the nucleus reaches a neutron closed-shell state. This state is similar to the closed shells of electrons in noble gas. Just as an atom of noble gas is chemically inactive and cannot interact with additional electrons, a neutron closed-shell nucleus has difficulty interacting with additional neutrons. Before the nucleus can capture another neutron, it must undergo beta decay, in which a neutron converts into a proton. The nucleus can now capture another neutron—an action that results in another neutron closed-shell nucleus, which also must decay before yet another neutron can be captured. This process may continue through several decay-and-capture cycles until a nucleus has the right number of protons and neutrons and can once again capture multiple neutrons.

Neutron closed-shell nuclei are referred to as r-process waiting-point nuclei. Once the nuclei can again capture multiple neutrons, they proceed along the path of many neutron captures and occasional beta decays. Eventually, they accumulate enough neutrons to reach the next neutron closed shell and the next set of waiting-point nuclei.

Because the flow of nuclei stalls at these points, waiting-point nuclei are the most abundant ones in the r-process. When the high neutron density of the r-process ends, these nuclei undergo a series of beta decays that ultimately produce the abundance peaks characterizing the r-process nuclei.

Unfortunately, accelerators cannot create nuclei so far from stability, which prevents scientists from studying waiting-point nuclei in the laboratory. However, some NIF experiments will produce extremely high neutron fluxes (about $10^{33}$ to $10^{34}$ neutrons per square centimeter per second) within about $10^{-10}$ second—all in a controlled laboratory environment. This short burn time will allow researchers to study the neutron-rich nuclei created in the r-process. The resulting data will help improve the accuracy of models that simulate the brief, violent life of an exploding star.

## Measuring the Mysteries of Stars

"Because of NIF, we're on the edge of an exciting time in nuclear science," says Bernstein. "We will be able to explore realms of nuclear physics that have been off limits to laboratory experiments. NIF will shine a light, so to speak, on two areas of the periodic table that have been dark for a long time."

*—Ann Parker*

**Key Words:** Coulomb repulsion, elements, fusion, hydrogen burning, National Ignition Facility (NIF), nucleosynthesis, periodic table, rapid (r) process, slow (s) process, stellar evolution, waiting-point nuclei.

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# Taking on the Stars

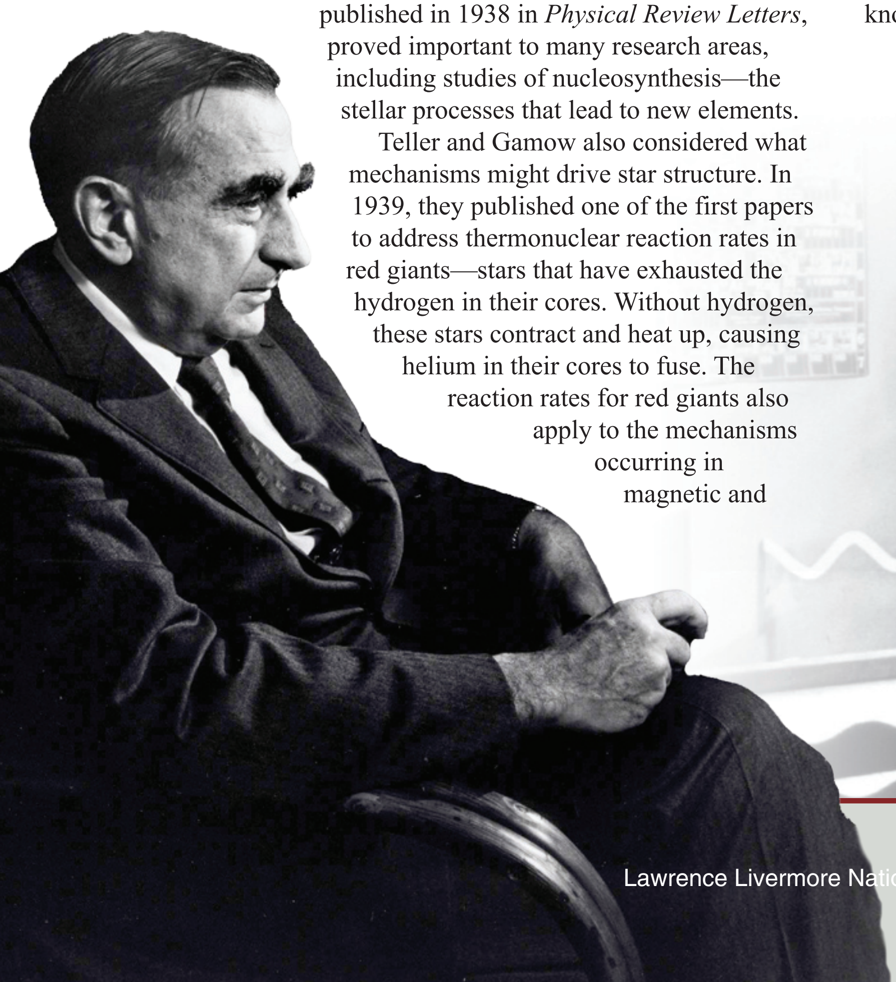
## Teller's Contributions to Plasma and Space Physics

*January 15, 2008, marks the 100th anniversary of Edward Teller's birth. This highlight is the fifth in a series of 10 honoring his life and contributions to science.*

IN *Memoirs*, Edward Teller recalls that the founding of Lawrence Livermore brought together physicists from two research areas: thermonuclear weapons design and controlled fusion. The broad set of physical processes studied in these fields also lies at the heart of astrophysics. Fusion reactions power the stars, and the temperatures and pressures occurring in stellar environments reflect those in an exploding nuclear device. As a result, insights made in one field often advance research in another.

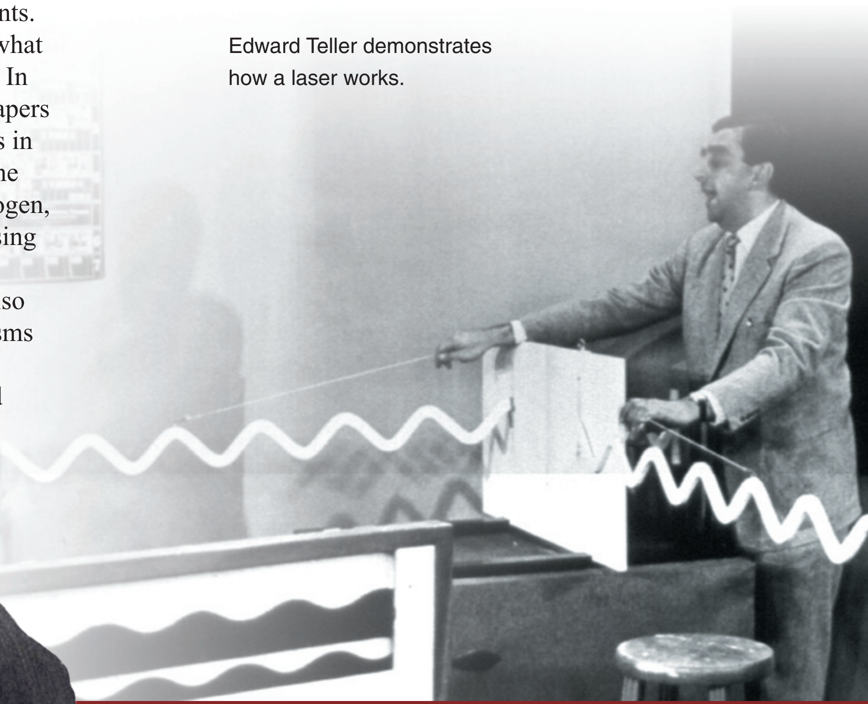
In the 1930s, many physicists, including Teller, applied the new mathematical tools of quantum mechanics to study the physical processes occurring in stars—how they form, evolve, and die and how they create new elements. While at George Washington University, Teller and George Gamow developed calculations for determining the rate of energy produced in thermonuclear fusion reactions in stars. The Gamow–Teller estimates, which they published in 1938 in *Physical Review Letters*, proved important to many research areas, including studies of nucleosynthesis—the stellar processes that lead to new elements.

Teller and Gamow also considered what mechanisms might drive star structure. In 1939, they published one of the first papers to address thermonuclear reaction rates in red giants—stars that have exhausted the hydrogen in their cores. Without hydrogen, these stars contract and heat up, causing helium in their cores to fuse. The reaction rates for red giants also apply to the mechanisms occurring in magnetic and laser fusion systems and in thermonuclear weapons. Although Gamow and Teller's preliminary hypothesis for red giants proved wrong, their work stimulated other ideas on star formation.



Teller's work with Gamow on basic nuclear physics also had a profound effect in astrophysics. The Gamow–Teller transitions, originally proposed as an addition to Enrico Fermi's theory of beta decay, helped researchers understand the proton–proton chain that powers the Sun.

Prior to World War II, Hans Bethe explained how fusion reactions create lightweight elements up to iron, which has 26 protons in its nucleus. Research indicated, however, that this type of nucleosynthesis did not apply to heavier elements. Astrophysics research declined during the war, as scientists turned their attention to national security missions. When the war ended, many renewed their studies of nucleosynthesis. In a 1949 paper published in *Physical Review*, Teller and Maria Mayer suggested that a fission process involving a neutron-rich nuclear fluid forms these heavy elements. Their hypothesis was a step toward today's theories explaining the slow and rapid neutron-caption mechanisms known as the s- and r-processes.



Edward Teller demonstrates how a laser works.

Teller tours the National Ignition Facility (NIF) with (left) Valerie Roberts, construction manager, and Ed Moses, associate director for NIF Programs.

At a star's inner core, extreme gravitational forces squeeze matter to high densities and temperatures. Understanding the physical processes occurring inside stars requires basic research on the physics of dense plasmas—another topic that captured Teller's interest. He and David Inglis explored how the conditions in a plasma might affect spectral data recorded in plasma experiments. In their 1939 paper published in *Astrophysical Journal*, they proposed that the bound electrons in a dense plasma—particularly those in orbits farthest from the nucleus—weakened their bonds. This change, which is caused by the electric fields from nearby ions and electrons, broadens the spectral lines of the outermost orbits. The Teller–Inglis hypothesis proved correct. Broadened lines appear in spectra of high-density plasmas in stars and in condensed-matter experiments.

At Los Alamos, Teller continued to study dense plasmas. Working with Richard Feynman and Nicholas Metropolis, he developed equations of state for elements at high pressures and various temperatures. Researchers in many disciplines, including astrophysics, continue to use the data tables in their much-cited paper, which was published in *Physical Review* in 1949.

In 1958, researchers discovered the existence of the Van Allen Belts—energetic charged particles trapped in orbit around Earth by the planet's magnetic field. Understanding the mechanisms holding these radiation belts in place is important to studies of Earth's near-space environment and to research on magnetic fusion machines designed to contain plasmas for long periods. In 1959, Teller and Theodore Northrop proposed that approximate conservation laws would force the motion of charges in Earth's magnetic field to be smooth and stable, thus leading to the stability of the Van Allen Belts. Later research indicated that chaotic motions are indeed possible. The role of the proposed conservation laws in these orbits is still under debate.

Another puzzle that captured Teller's attention concerned the origin of cosmic rays, energetic particles that impinge on Earth's atmosphere and the interstellar medium. In 1949, he and Robert Richtmyer proposed a model for cosmic-ray generation near the Sun. Other researchers, including Fermi, suggested coherent mechanisms for cosmic-ray acceleration over interstellar and galactic scales. All of these theories relied on the equations developed by Teller and Frederic de Hoffmann to explain shock-wave behaviors in magnetized plasmas.

Given Teller's interest in plasma physics and the nature of stars, it is no surprise that astrophysics found a home at Livermore. Some of the first shock-physics experiments at the National Ignition Facility will examine these extreme environments. (See the highlights beginning on pp. 20 and 22.) Results from those experiments will also benefit the Laboratory's national security missions. As Teller says in *Memoirs*, "Livermore has emphasized astrophysics and other branches of pure science in the recognition that great progress in applications cannot be made if science itself is neglected."

—*Ann Parker*

**Key Words:** astrophysics, controlled fusion, Edward Teller, thermonuclear weapons.

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*Continued from p. 2*

## Laboratory joins California Hazards Research Institute

As California's population grows, so does the threat that natural hazards—earthquakes, tsunamis, volcanic eruptions, wild fires, floods, storms, and droughts—could turn into major catastrophes. The Laboratory is collaborating with 10 University of California (UC) campuses and 3 national laboratories to form the California Institute for Hazards Research (CIHR), a multicampus research program that will focus on all aspects of disaster research, planning, and preparedness.

CIHR will collaborate with state, federal, and international organizations on natural disaster research and education. It will encourage partnerships across the UC system and integrate them into an overall strategic plan. Research areas will include understanding and forecasting natural hazards, reducing the effect of natural disasters, strengthening emergency-response and public health systems, and improving long-term recovery and rebuilding.

John Rundle, director of the UC Davis Center for Computational Science and Engineering, leads the recently approved institute. According to Livermore geophysicist Doug Rotman, who leads the Laboratory's work for the institute, the range of capabilities offered by the UC campuses and national laboratories will allow CIHR to comprehensively address hazards that threaten California. Livermore will contribute its expertise in chemistry, physics, atmospheric science, and national security to this collaborative effort.

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## Understanding the Pacific Ocean's Ring of Fire

Laboratory scientist Megan Flanagan is working with UC Santa Cruz researchers to uncoil the geophysical and geochemical mysteries of the Pacific Ocean's Ring of Fire. This 40,000-kilometer-long area of frequent earthquakes and volcanic eruptions results in a nearly continuous series of oceanic trenches, island arcs, and volcanic mountain ranges and plate movements. Ninety percent of the world's earthquakes and 81 percent of the largest ones occur along the Ring of Fire.

By looking at earthquakes deep in the Pacific plate's lithosphere (the outer shell of Earth's mantle), Flanagan and her colleagues developed a three-dimensional model of the highest velocity primary and secondary waves moving through a subsurface area called the Tonga subduction zone. The zone is located between the Pacific plate and the northeastern corner of the Australian plate. When the Pacific plate subducts beneath the Australian plate, the overlying mantle wedge (the Tonga wedge) undergoes localized partial melting and ascent of magmas. As a result, island or continental arcs are produced.

The Pacific plate has been sinking at the Tonga subduction zone for 40 million years at a rate of about 15 centimeters per year. However, the northern portion has the fastest plate velocity recorded on the planet, sinking 25 centimeters per year. Using seismic waves from deep earthquakes in this region, the research team illustrated the structural and chemical complexity of the wedge. Their research, which appeared in the May 11, 2007, edition of *Science,* demonstrated the structure and processes essential for understanding the flow pattern of mantle material in the Tonga wedge. New images will also help researchers characterize the wedge dynamics and chemistry in this area.

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# Patents and Awards

*Each month in this space, we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.*

## Patents

### Optically Triggered Fire Set/Detonator System
**Jay B. Chase, Philip A. Pincosy, Donna M. Chato, Hugh Kirbie, Glen F. James**
U.S. Patent 7,191,706 B2
March 20, 2007
This system has multiple capacitor discharge units (CDUs) that include electrical-bridge-type detonators coupled to explosives. A pulse-charging circuit provides a voltage for each capacitor in a CDU. The capacitors are discharged through the electrical-bridge-type detonators when they receive an optical signal to detonate the coupled explosives at the same time.

### Apparatus for Stopping a Vehicle
**Willard H. Wattenburg, David B. McCallen**
U.S. Patent 7,191,862 B2
March 20, 2007
This apparatus externally controls brakes on a vehicle that has a pressurized fluid braking system. It can include a pressurized vessel that is adapted for fluid-tight coupling to the braking system. Fluid pressures in the braking system can be modified to stop the vehicle and render it temporarily inoperable by impacting the rear of the vehicle with a pursuit vehicle, shooting a target mounted on the vehicle, or sending a signal from a remote control. A control device placed in the driver's compartment of a vehicle can also render the vehicle inoperable and cannot be disabled by a driver or hijacker.

### High Precision, Rapid Laser Hole Drilling
**Jim J. Chang, Herbert W. Friedman, Brian J. Comaskey**
U.S. Patent 7,193,175 B1
March 20, 2007
This laser system produces a first laser beam that rapidly removes the bulk of material in an area, forming a ragged hole. The laser system produces a second laser beam that accurately cleans up the ragged hole so that the final hole has highly precise dimensions.

### Multi-Pulse Multi-Delay (MPMD) Multiple Access Modulation for UWB
**Farid U. Dowla, Faranak Nekoogar**
U.S. Patent 7,194,019 B2
March 20, 2007
This new modulation technique uses multiple orthogonal transmitted-reference pulses for channeling ultrawideband (UWB) communications. The proposed UWB receiver samples the second-order statistical function at both zero and nonzero lags and matches the samples to stored second-order statistical functions. It thus samples and matches the shape of second-order statistical functions rather than only the shape of the received pulses.

### Wavelength-Conserving Grating Router for Intermediate Wavelength Density
**Robert J. Deri, Rajesh R. Patel, Steven W. Bond, Corey V. Bennett**
U.S. Patent 7,194,161 B1
March 20, 2007
A wavelength router used as a fiber-optic networking router is based on a diffraction grating that uses only $N$ wavelengths to interconnect $N$ inputs to $N$ outputs. The basic approach augments the grating with additional couplers or wavelength-selective elements so that $N - 1$ of the $2N - 1$ outputs are combined with other $N$ outputs (leaving only $N$ outputs). One design uses directional couplers as combiners. Another uses wavelength-selective couplers. In a third setup, a pair of diffraction gratings maintains parallel propagation of all optical beams. Beams can be combined using retroflection back through the grating pair or using couplers.

### Adaptive Ophthalmologic System
**Scot S. Olivier, Charles A. Thompson, Brian J. Bauman, Steve M. Jones, Don T. Gavel, Abdul A. S. Awwal, Stephen K. Eisenbies, Steven J. Haney**
U.S. Patent 7,195,354 B2
March 27, 2007
This system for improving vision can diagnose monochromatic aberrations in a subject's eyes and apply the wavefront correction so the patient can view the correction results. The system uses a laser to produce a beam of light. It also has a corrector, a wavefront sensor, and a testing unit. An optic device directs the light beam to the corrector and then to the retina, the wavefront sensor, and the testing unit. A computer connects the wavefront sensor to the corrector.

## Awards

Livermore physicist **Hope Ishii** received the **2007 Outstanding Woman in Science** from the **Alameda County Women's Hall of Fame** for her work as part of the Laboratory's Stardust team. The National Aeronautics and Space Administration launched the Stardust mission in February 1999. The spacecraft captured particulate materials from the comet Wild 2 on January 2, 2004. Returned to Earth in 2006, these samples offer a glimpse of the building materials available around the time the planets formed.

**Jennifer Giocondi**, a postdoctoral researcher in the Glenn T. Seaborg Institute of the Chemistry, Materials, and Life Sciences Directorate, received the **Best Poster Award** at the **Materials Research Society Spring Meeting**. In her presentation, Giocondi quantified how magnesium impurities affect the growth of the rare mineral brushite and pinpointed the mechanisms in which magnesium influences the kinetics of mineralization.

The **International Society for Optical Engineering (SPIE)** has selected Laboratory scientist **Scot Olivier** as a **Fellow** for his achievements in adaptive optics. Olivier leads the Adaptive Optics Group in Livermore's Physics and Advanced Technologies Directorate and has made significant contributions in applying adaptive optics to astronomy, human vision science, high-power lasers, and remote sensing. He also serves as the chair of the SPIE Adaptive Optics Technical Group and as an associate director of the Center for Adaptive Optics at the University of California at Santa Cruz.

In a ceremony at the Pentagon, Livermore's **Hriar Cabayan** received the **highest civilian award** given by the **chairman** of the **Joint Chiefs of Staff**. The award honored Cabayan for his decade of service to the nation. Cabayan works in the Laboratory's National Security Office, supporting the Defense Secretary's Director of Defense Research and Engineering. He also manages an effort to provide long-term planning support to Combatant Commands for the Office of the Secretary of Defense and the U.S. Strategic Command.

## Abstracts

### Preparing for the X Games of Science

The National Ignition Facility (NIF) will provide researchers from universities and Department of Energy national laboratories unparalleled opportunities to explore the frontiers of basic science. Most NIF experiments will be devoted to stockpile stewardship efforts. However, a significant percentage of shots will focus on basic science research in fields such as astrophysics, planetary physics, hydrodynamics, nonlinear optical physics, materials science, and inertial confinement fusion. With 192 beams generating up to 2 megajoules of energy, NIF will allow scientists to explore some of the most extreme conditions in the universe such as the hot, dense plasmas found in stars. Each NIF experimental series will require different laser parameters such as wavelength, energy, and pulse duration as well as beam configurations, targets, and diagnostic instruments. By taking advantage of the facility's experimental flexibility, research teams will be able to create an extraordinary range of physical environments.

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### Meeting the Target Challenge

The National Ignition Facility (NIF) is a one-of-a-kind scientific laboratory, able to create the temperatures, pressures, and densities of an exploding nuclear weapon or the interior of a large planet. Livermore target designers, materials scientists, and engineers are working together to create the miniscule targets needed for NIF experiments. The millimeter-size targets must be machined to meet precise requirements, including specifications for density, concentricity, and surface smoothness. Material scientists often create a material for a specific design. Fabrication engineers then determine whether the material can be machined and assembled. Throughout the design process, engineers inspect target materials and components using nondestructive diagnostics to ensure that specifications are met and that components are free of defects. Together, this multidisciplinary team takes an experimental target from concept to reality.

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***Jeff Atherton (925) 423-1078 (atherton1@llnl.gov) or Alex Hamza (925) 423-9198 (hamza1@llnl.gov).***

## Coming Next Month

# Directing Hydrodynamic Experiments

Ramrods combine technical training and project management skills to oversee the design and execution of hydrodynamic tests.

*Also in September*

*• New nanolithographic techniques are joining Livermore's current expertise in microlithography.*

*• Scientists in the homeland security community join forces to assess the probable effects of a biological attack.*

*• A novel spectrometer is designed to illuminate the nature of dark matter, which may account for up to 90 percent of the mass in the universe.*

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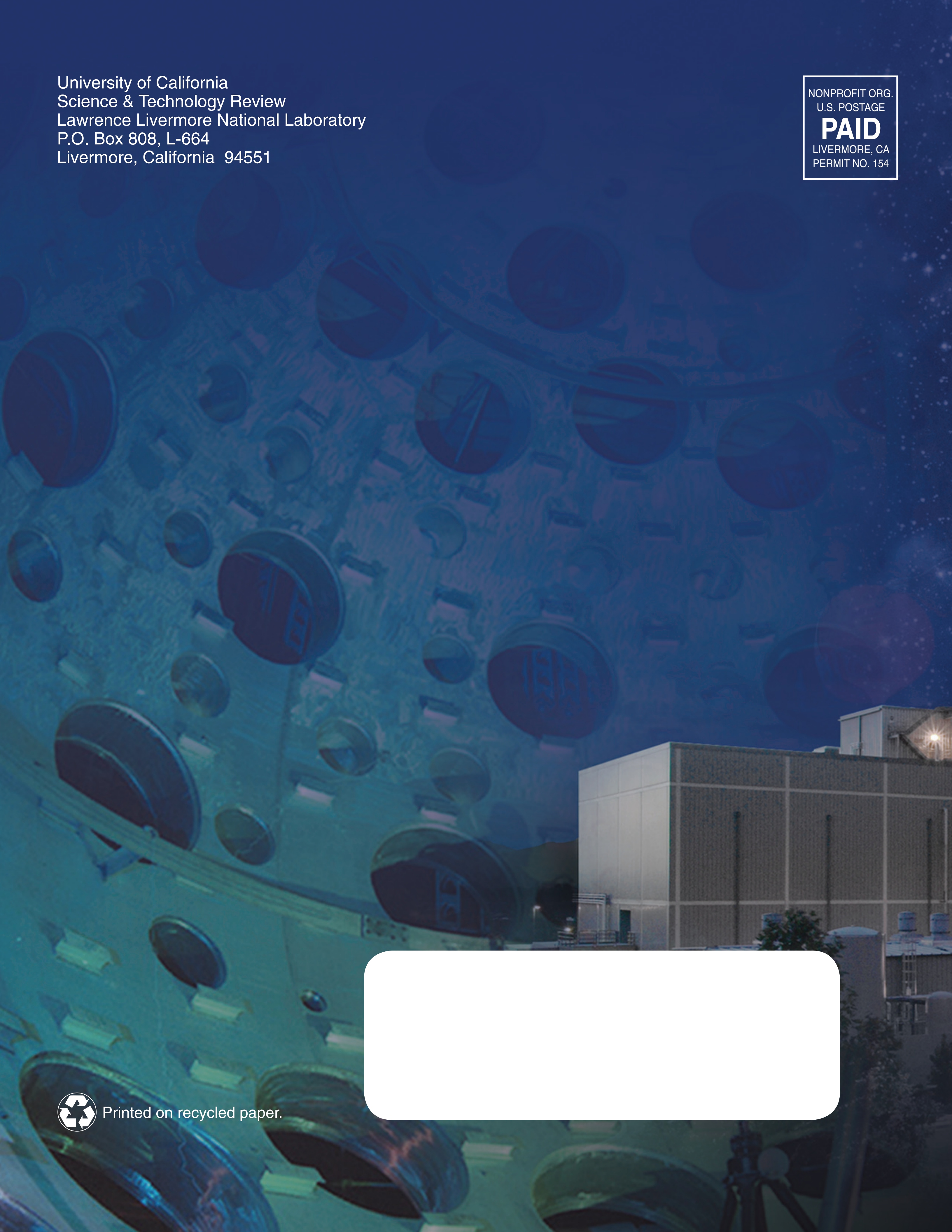

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